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2

THE ATCHAFALAYA RIVER DELTA

Report 12

TWO-DIMENSIONAL MODELING OF ALTERNATIVE PLANS AND IMPACTS ON THE ATCHAFALAYA BAY AND TERREBONNE MARSHES

by

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13. ABSTRACT *(Maximum 200 words)*
The Wax Lake Outlet and Atchafalaya River deltas in Louisiana have grown dramatically, and concern over the impact of this growth has led the US Army Corps of Engineers to conduct an investigation to predict how the deltas will evolve over the next 50 years. An additional task was to determine the impacts of that growth on navigation, flood control, salinity, and sedimentation in the bay area. The technical approach for this investigation builds upon the TABS-2 finite element numerical modeling system and is fully described in Report 11 of this series. Comparisons of the existing condition results with various alternatives are presented. In summary, the extension of the Avoca Island Levee to Deer Island (Reach 2) resulted in an approximate 8 percent increase in the predicted size of the 50-year delta evolution regardless of other constraints tested. For all alternatives tested, the size of the 50-year subaerial delta fell within the bounds of 56 to 144 square miles. The most extreme delta evolution simulation tested was the condition
(Continued)

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without the Wax Lake Outlet flow control project, no navigation channel dredging, and no levee extension. For all delta evolution simulations tested, the water surface elevations within areas east of the levee increased from 3.4 to 6.0 ft by year 2030. In each case tested, the Avoca Island Levee Extension to Reach 2 decreased the backwater effect of the 50-year delta by approximately 2 ft.

14. (Concluded).

Terrebonne Marshes
Wetland hydronynamics

PREFACE

The work reported herein was performed in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) as a part of the overall investigation to predict the evolution of the Atchafalaya Bay delta for the US Army Engineer District, New Orleans (LMN). This report presents the results of the two-dimensional numerical modeling work.

The study was conducted under the direction of the following personnel: Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory; W. H. McAnally, Chief of the Estuaries Division, Hydraulics Laboratory; J. V. Letter, Chief of the Estuarine Simulation Branch, Estuaries Division, and Technical Advisor; and Project Managers S. A. Adamec and Ms. B. P. Donnell, Estuarine Simulation Branch.

The following Hydraulics Laboratory individuals contributed to the preparation of this report: S. A. Adamec, D. P. Bach, B. P. Donnell, J. V. Letter, W. H. McAnally, and A. M. Teeter. This report was prepared by Ms. Donnell and Mr. Letter.

Consultants to the project were Mr. H. B. Simmons, Mr. L. R. Beard, Dr. R. B. Krone, Dr. C. R. Kolb, and Mr. F. B. Toffaleti. Mr. B. J. Garrett and Ms. N. Powell of LMN served as the District's project coordinator. This effort was coordinated with the US Fish and Wildlife Service and the Center for Wetland Resources, Louisiana State University, Baton Rouge, LA, through LMN.

The numerical modeling effort was initiated in 1980 on the CRAY-1 computer at Boeing Computer Services, and terminated in 1989 on the Cyber-205 computer at Power Computing Company, formerly Scientific Information System, which was formerly Control Data Corporation headquartered in Minneapolis, MN.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.07645549	cubic metres
feet	0.3048	metres
knots (international)	0.514444	metres per second
miles (U.S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles (U.S. statute)	2.589998	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

THE ATCHAFALAYA RIVER DELTA

TWO-DIMENSIONAL MODELING OF ALTERNATIVE PLANS AND IMPACTS ON THE ATCHAFALAYA BAY AND TERREBONNE MARSHES

PART I: INTRODUCTION

Objectives

1. The objectives of the Atchafalaya Bay investigation are to answer these questions:

   For existing conditions and no actions other than those already practiced (i.e., maintenance of navigation channels), how will the deltas evolve over the short-to-medium term (10-15 years) and the long term (50 years)?

   b. How will the deltas' evolution affect:

      (1) Flood stages?

      (2) Maintenance dredging of the navigation channel?

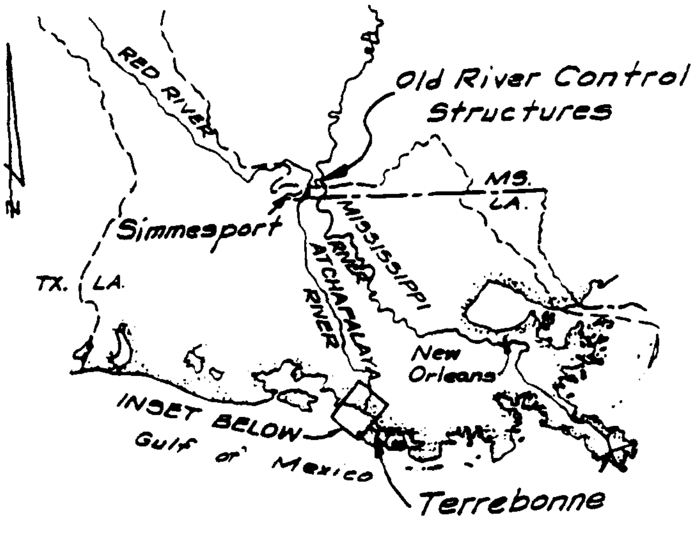
      (3) Salinity, sedimentation, and circulation in the Atchafalaya Bay system?

   c. What would be the impact of various alternatives on all of the above?

2. This report builds upon the work outlined and described in Report 11 of this series (Donnell, Letter, and Teeter 1991). Within Report 11, each of the principal models' verification to field observations and the short-term and long-term extrapolation technique were shown to be credible. This report will describe the various alternative plan testing used for this investigation and compare the effects of these plans with the Base condition described in Report 11.

Background

3. The Atchafalaya River carries about 30 percent of the combined flows of the Mississippi River and Red River at the latitude of 31 degrees north (near Simmesport, Figure 1). This flow split is enforced by the Old River Control Structures, and is held constant for this study. The Atchafalaya



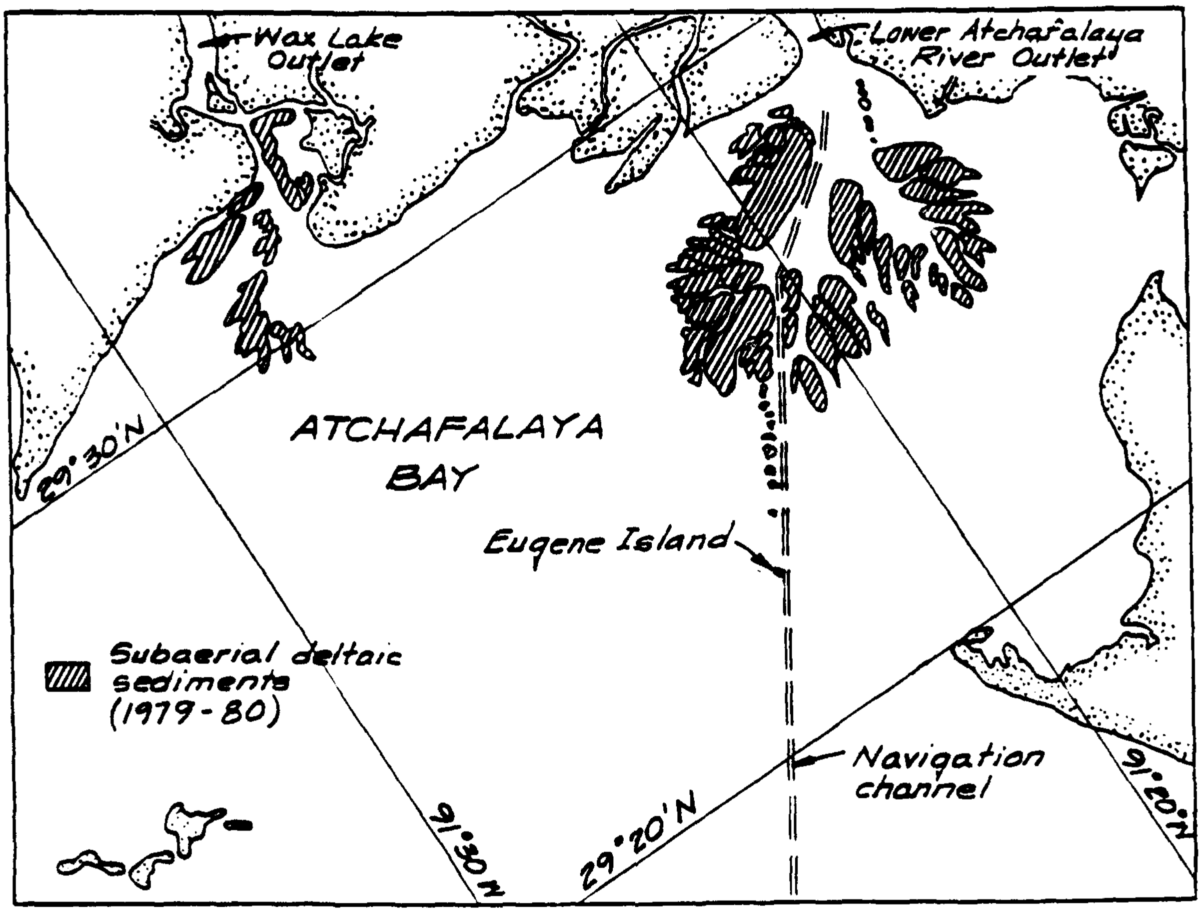


Figure 1. Vicinity sketch showing the Atchafalaya River and Wax Lake Outlet deltas

River carries with it an average of 100 million tons* of sediment (Keown, Dardeau, and Causey 1981) in suspension each year. Progressively, the sediment load has filled in the Atchafalaya basin floodway between its natural and manmade levee systems over the past several decades and is now depositing rapidly in Atchafalaya Bay (Figure 1 enlargement). As shown, there are two deltas forming in Atchafalaya Bay: at the mouths of Lower Atchafalaya River (LAR) and Wax Lake Outlet (WLO). The evolving deltas became subaerial in 1973 and soon after vegetated and have since become one of the most dynamic currently active delta systems in the world. The evolving deltas have converted shallow bays into marshes and continue to generate a great deal of interest in deltaic processes. The primary benefit from these two deltas has been the addition of new land to the coast of Louisiana in areas traditionally experiencing land loss. The primary concerns with the evolving deltas have been siltation in the navigation channels and backwater flooding in the surrounding low-lying coastal parishes of southern Louisiana.

4. Phenomenal growth of the subaerial LAR delta and the emerging WLO delta led the US Army Engineer District (USAED), New Orleans, to request that the US Army Engineer Waterways Experiment Station (WES) conduct a thorough investigation to predict future growth of the deltas and effects of that growth.

Technical Approach

5. The plan of investigation includes the following multiple techniques to predict delta growth:

- a. Extrapolation of observed bathymetric changes into the future.
- b. A generic analysis that predicted future delta growth by constructing an analogy between behavior of the Atchafalaya delta and other deltas in similar environments.
- c. Analytical treatment of a sediment-laden jet discharging into a quiescent bay.
- d. Quasi-two-dimensional numerical modeling of hydrodynamics and sedimentation processes.
- e. Two-dimensional numerical modeling of hydrodynamics and sedimentation processes considering riverflow, tides, Gulf levels,

* A table of factors for converting non-SI units of measurements to SI (metric) units is presented on page 3.

storm surges, wind-induced currents, wind waves, salinity, and subsidence.

Each of these built upon prior work and employed a progressively greater degree of sophistication. A basic description of the overall plan is given by McAnally, Heltzel and Donnell (1991) (Report 1 of this series). Although separate reports have been published on each technique, a summary of approaches a, b, and d is given in Report 6 of this series (McAnally et al. 1984). A list of all reports of this series is found in Table 1.

Modeling Approach

6. The 2-D finite element (FE) modeling approach used to predict the short (10-15 years) and long-term (50 years) evolution of the Lower Atchafalaya River and Wax Lake Outlet deltas is the product of years of modeling development, field investigations, and modeling experience. Report 11 (Donnell, Letter, and Teeter 1991) verified the application of the 2-D modeling system to the Atchafalaya Bay and Terrebonne Marshes. The models used for this study were elements of the TABS-2 Numerical Modeling System, (Thomas and McAnally 1985). Verification included separate real-time* simulations of the principal numerical models employed: the hydrodynamic model (RMA-2), the sediment transport model (STUDH), and the salinity model (RMA-4). In addition, the long-term evolution simulation, based on a statistical ensemble of real-time sediment transport modeling, was verified to historical delta evolution (1967-1977) and to LAR navigation channel dredging records (1973-1985). A full explanation of the long-term modeling approach is provided in Report 11 of this series and summarized in Figure 2.

7. Note that delta growth bathymetric predictions were made in a run-extrapolate-run fashion with real-time computation occurring at year 0 (1980), year 15 (1995), year 30 (2010), and year 50 (2030). The events used for the long-term delta growth bathymetric predictions are given in Table 2. The combined discharge listed in Table 2 is the total discharge of the WLO and LAR as recorded at Simmesport, LA. Gulf Level indicates whether the mean level of the Gulf of Mexico was high (0.5 ft NGVD) or mean (0 ft NGVD) during the test event.

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* As used here, real-time means flow and transport calculations made by successive time-step solutions of the time-varying, non-linear governing equations. It does not imply calculations proceeding at the same speed as natural clock time.

Table 1

Reports in this Series*

Report No.	Reference		Subtitle	Contents
1	McAnally, Heltzel and Donnell	1991	A Plan of Predicting the evolution of Atchafalaya Bay, Louisiana	Methods and approach
2, Section 1	Coleman et al.	1988	Field Data: Atchafalaya Bay Bay Program Description and Data [2 volumes]	Field data collection methods and presentation of data (4 Sections)
2, Section 2	Teeter and Pankow	1989	Field Data: Settling Characteristics of Bay Sediments	
2, Section 3	Pankow, Teeter, Donnell and Adamec	1990	Field Data: Grain Size Analysis of Selected Bay Sediments	
2, Section 4	Bensen and Donnell	1990	Field Data: Terrebonne Marshes Program Description and Data	
3	Letter	1982	Extrapolation of Delta Growth	Analytical extrapolation of historical behavior
4	Wells, Chinburg, and Coleman	1984	Generic Analysis of Delta Growth	Comparison with similar deltas to identify stage of development and predict future trends
5	Thomas, Heath, Stewart and Clark	1988	Quasi-Two Dimensional Modeling of Delta Growth and Impacts an River Stages	Quasi-two dimensional hydrodynamic and Sedimentation river flow modeling

(Continued)

* All Atchafalaya reports are published under the main title, "The Atchafalaya River Delta," Technical Report HL-82-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1 (Concluded)

Report No.	Reference	Subtitle	Contents
6	McAnally, Thomas, Letter and Stewart 1984	Interim Summary Report of Growth Predictions	Summary and analysis of Reports 3, 4, and 5
7	Wang 1985	Analytical Analysis of the Development of the Atchafalaya River Delta	Analytical treatment of a simple jet discharging into a quiet bay
8	Ebersole 1985	Numerical Modeling of Hurricane-Induced Storm Surge	Two-dimensional modeling hurricane induced storm surge
9	Ebersole 1985	Wind Climatology	Predictions of wind conditions over the bay
10	Jensen 1985	Wave Hindcasts (3 Appendices)	Modeling of locally-Generated Wind Waves
11	Donnell, Letter and Teeter 1991	Two-Dimensional Modeling (1 Appendix)	Two-dimensional finite element modeling of hydrodynamics, salinity, and sedimentation
12	Donnell and Letter 1992	2D Modeling of Alternative Plans and Impacts on the Atchafalaya Bay and Terrebonne Marshes	Employs the tools described in Report 11, and shows the effects of plans
13	Donnell and Letter 1992	Summary Report of Delta Growth Predictions	Summary and analysis of all delta growth predictions conducted during this investigation

Flowchart of the RUN-EXTRAPOLATE-RUN Process

```
          Define Bathymetry Year=1980
                      |
                      v

        Define Hydrodynamic Event(I)    <------+
                      |                        |
                      v                        |
       Define Sedimentation for Event(I)       |
                      |                        |
                      v                        |
              < ALL Events? >       NO  -------+
                      |
                      v

     Extrapolate Bathymetry to Year=1995
                      |
                      v

        Define Hydrodynamic Event(I)    <------+
                      |                        |
                      v                        |
      Define Sedimentation for Event (I)       |
                      |                        |
                      v                        |
              < ALL Events? >       NO  -------+
                      |
                      v

     Extrapolate Bathymetry to Year=2010
                      |
                      v

        Define Hydrodynamic Event (I)    <-----+
                      |                        |
                      v                        |
       Define Sedimentation for Event(I)       |
                      |                        |
                      v                        |
              < ALL Events? >       NO  -------+
                      |
                      v

     Extrapolate Bathymetry to Year=2030
                      |
                      v

   50-YEAR DELTA GROWTH PREDICTION COMPLETED
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Figure 2. Summary of the long-term modeling approach

Table 2

Events Used for Long-Term Delta Evolution Predictions

Event Number	Combined Discharge cfs	Gulf Level Mean	Gulf Level High	Sediment Type Noncohesive	Sediment Type Cohesive
1	570,000	*		*	
2	570,000	*			*
3	330,000	*		*	
4	330,000	*			*
5	150,000	*			*
6	78,000	*			*
7	78,000		*		*

8. Principal aspects of the TABS-2 50-year delta evolution simulations presented and compared in this report are summarized below:

Hydrodynamic

a. RMA-2 was verified with multiple discharge and tidal conditions to prototype tide and velocity data (1980-1986) encompassing the entire modeling domain.

b. Five hydrodynamic events were modeled with discharges ranging from 78,000 to 570,000 cfs.

c. Synthesized Gulf boundary conditions (25-hour repetitive tidal cycle with mean range) were derived from harmonic analysis of prototype tidal data.

d. Non-reflecting riverine boundary module was used at the Calumet (WLO) and Morgan City (LAR) inflow boundary.

e. Manning's n roughness ranged from 0.01 to 0.06 for navigable waters and 0.2 to 0.5 for marsh and/or subaerial delta lobes.

f. Eddy viscosity values ranged from 25 to 750 lb-sec/ft^2 largely based upon element size.

g. Wetting/drying of subaerial delta and marsh zones with tidal fluctuations in the water levels was handled on an elemental basis.

Salinity

a. RMA-4 salinity concentrations were verified to prototype data for discharge events of 78,000 and 330,000 cfs.

b. Discharge events of 78,000, 150,000, and 330,000 cfs at Simmesport were modeled.

c. 350-hour simulations were made with the extended time-stepping technique which used residual (net) currents averaged over a full tidal cycle.

d. Offshore boundary conditions were determined from long-term field data.

e. Diffusion coefficients ranged from 100 to 200 sq m/sec.

Sediment

a. STUDH concentrations were verified to specific mean discharge prototype events, maintenance dredging to a 13-year average prototype LAR channel dredging records (1973-1985), and delta evolution to a 10-year prototype rapid delta growth period (1967-1977).

b. Both cohesive and noncohesive sediments were modeled.

c. Inflow boundary sediment concentrations for each discharge event were determined by the quasi-2D work described in Report 5 of this series (Thomas et al. 1988).

d. Sedimentation coefficients were determined by analysis of prototype samples.

Extrapolating into the future

a. Extrapolation was used to project delta evolution predictions from year 0 to 15, from year 15 to 30, and from year 30 to 50, with hydrodynamic and sediment modeling of revised bathymetry at the end of each projection.

b. The discharge probabilities for each event were combined with wave height probabilities in a joint-probability statistical approach.

c. Predicted bed change from the STUDH model was extrapolated within the long-term delta evolution window (Figure 3).

d. Spatially varying subsidence rates (Figure 4) were subtracted from the predicted bed change within the long-term delta evolution window, as described in (c) above.

e. The maximum allowable extrapolated subaerial height was 2.5 ft above NGVD.

f. A smoothing factor was applied to the outer bay to alleviate exaggerated depth gradients in large elements after an extended extrapolation period.

Computational meshes

9. Figure 5 shows MESH7, the computational mesh that defines the modeling domain used to simulate delta growth from year 0 through year 15. It contained 4694 nodes and 1539 elements and featured a 3000 ft wide dredge material disposal area on both sides of the LAR navigation channel from the coastline to Eugene Island.

10. Mid-way into the long-term predictions of the delta growth the

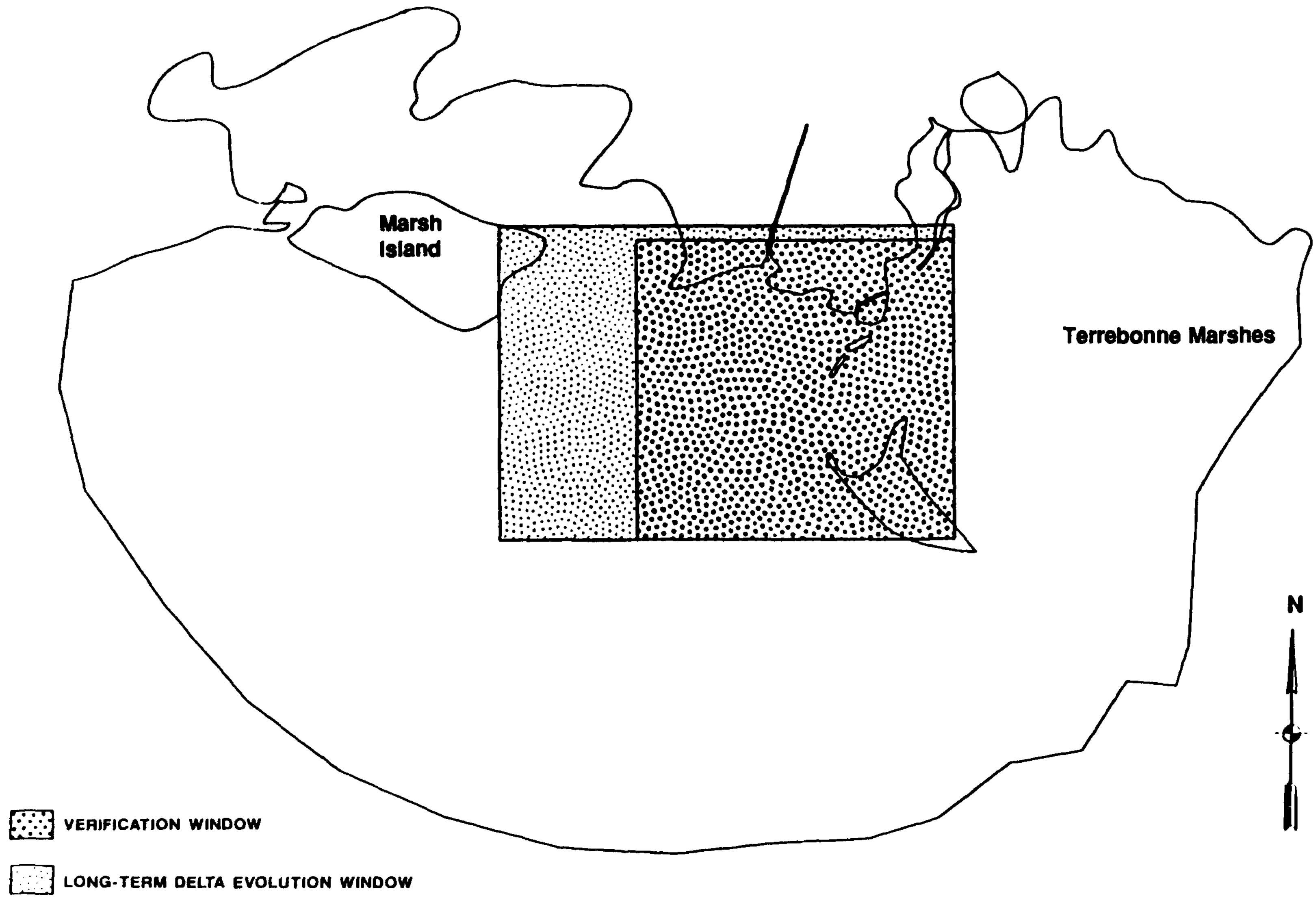
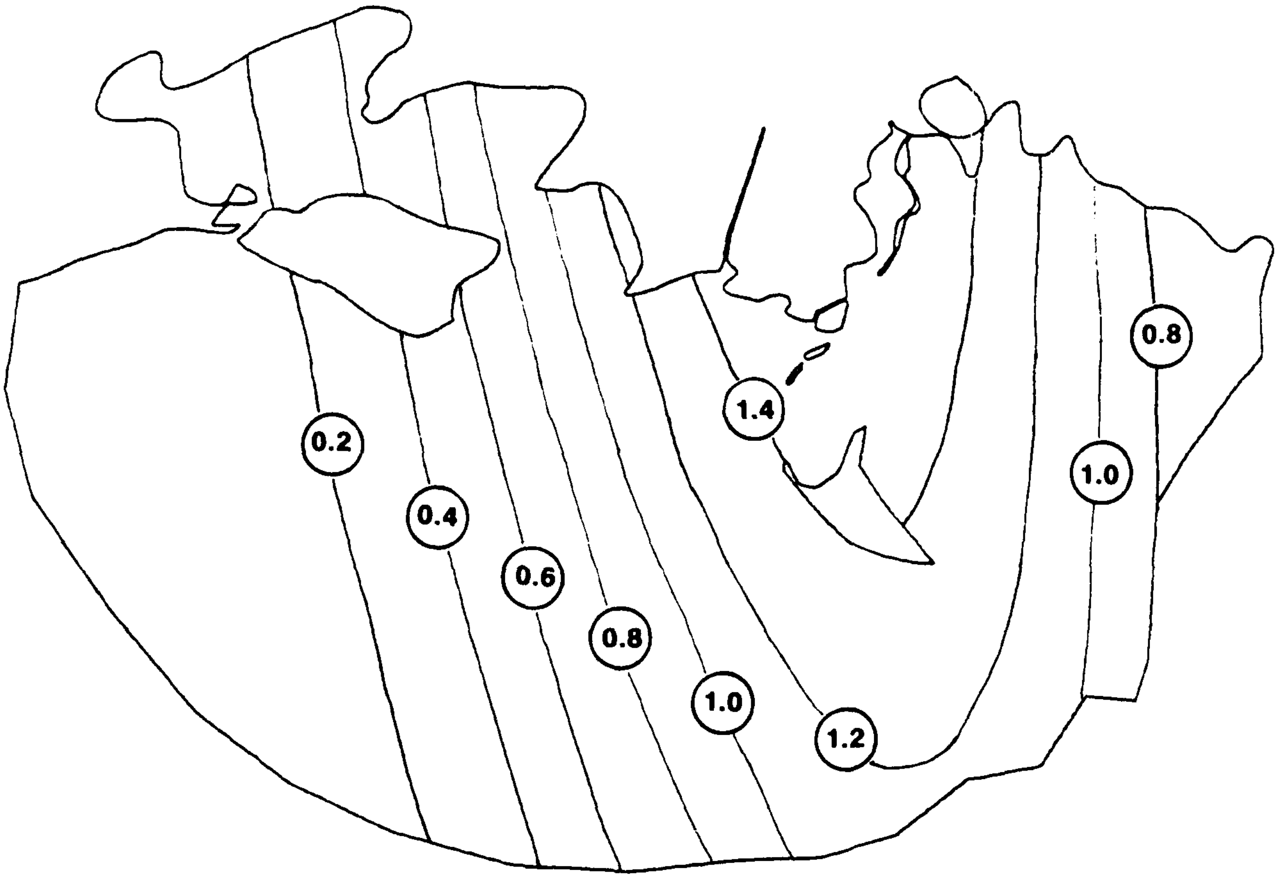


Figure 3. Extrapolation windows



Apparent Subsidence (cm/year)

For k= 10^{-8} and To=28,500 days

For 1962 to 2030

Figure 4. Spatially varying subsidence rates derived by regression analysis of prototype stage data (Report 11, Appendix A, of this series)

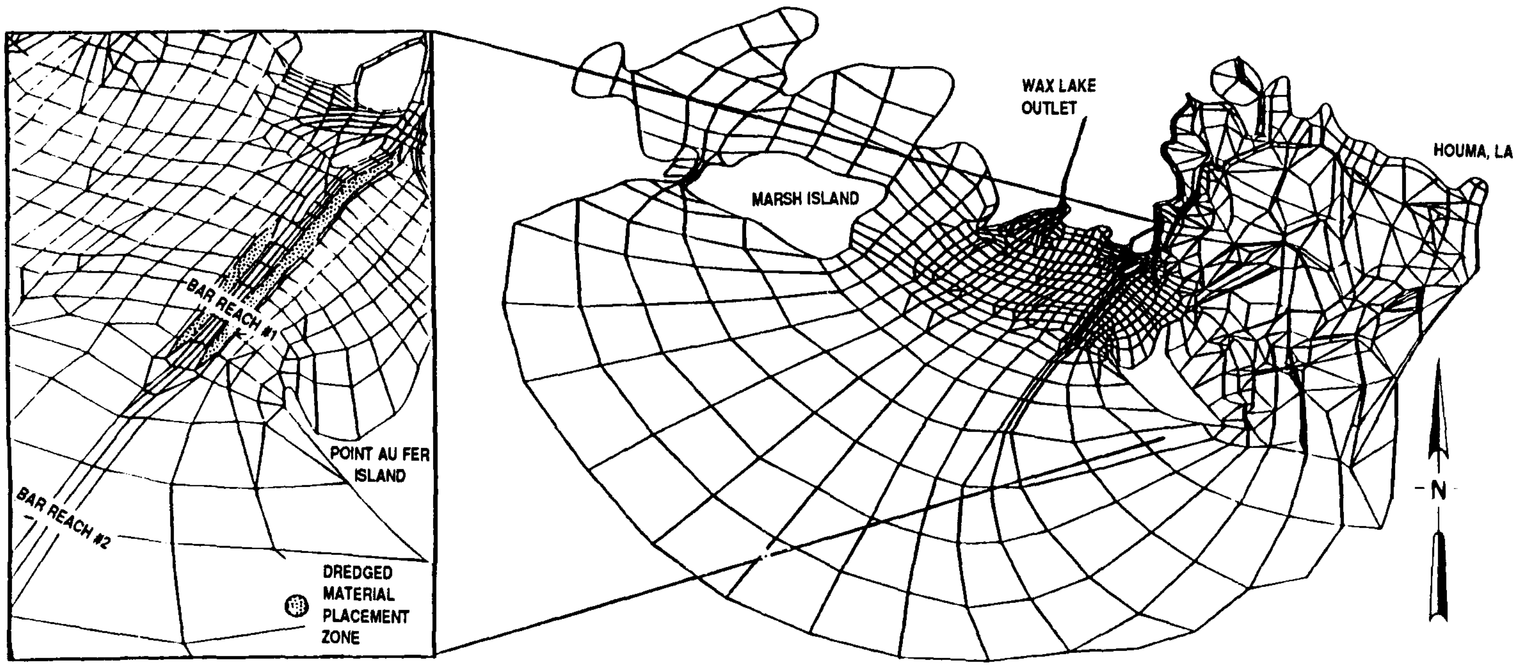


Figure 5. Numerical computational MESH7 for the Atchafalaya Bay and Terrebonne Marshes with a 3,000-ft-wide dredge disposal zone

disposal areas filled to capacity. After consultation with LMN concerning the in-filling of the 3000-ft disposal areas, MESH7 was modified to widen the disposal areas to 6000 ft and to extend those areas to Bar Reach 2. Figure 6 shows the revision, MESH8, with a detailed view of the Atchafalaya Bay channel. The refined MESH8 schematization of the Atchafalaya Bay - Terrebonne Marsh computational network, with 4806 nodes and 1583 elements, was used for delta growth predictions in years 30 and 50.

11. MESH9 was developed to test the project flood flow in the Atchafalaya Basin. MESH9 (Figure 7) consisted of the same basic resolution as MESH8 except with an additional western overbank area along the Lower Atchafalaya River. MESH9 consisted of 1735 elements and 5217 nodes.

12. These meshes provided an expanding capability to simulate the long-term evolution of the delta and subsequently provided a basis for isolating and identifying the impacts of various aspects of man's control efforts on the system.

Scope

13. This report presents the results of the 2D numerical model simulations for alternative features of the project. The verification of the modeling techniques was presented in Report 11 of this series (Donnell, Letter, and Teeter 1991), and this report presents the findings of the application of these tools to the project alternatives. The alternatives studied include the extension of the Avoca Island Levee, the Wax Lake Outlet flow control structure, Bayou Boeuf lock operations, and dredged material placement.

14. The concluding remarks of this document address comparisons, trends, and impacts of the alternatives tested.

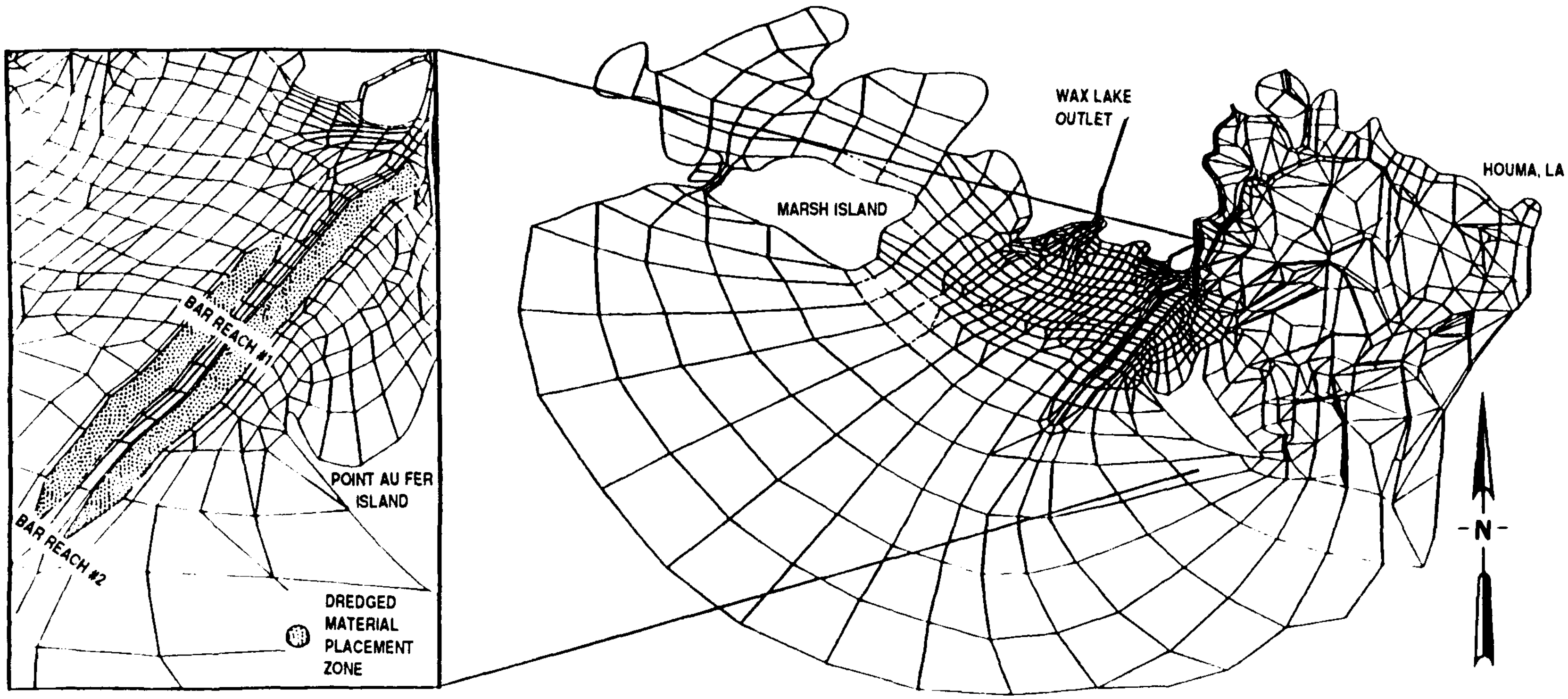


Figure 6. Numerical computational MESH8 for the Atchafalaya Bay and Terrebonne Marshes with a 6,000-ft-wide dredge disposal zone

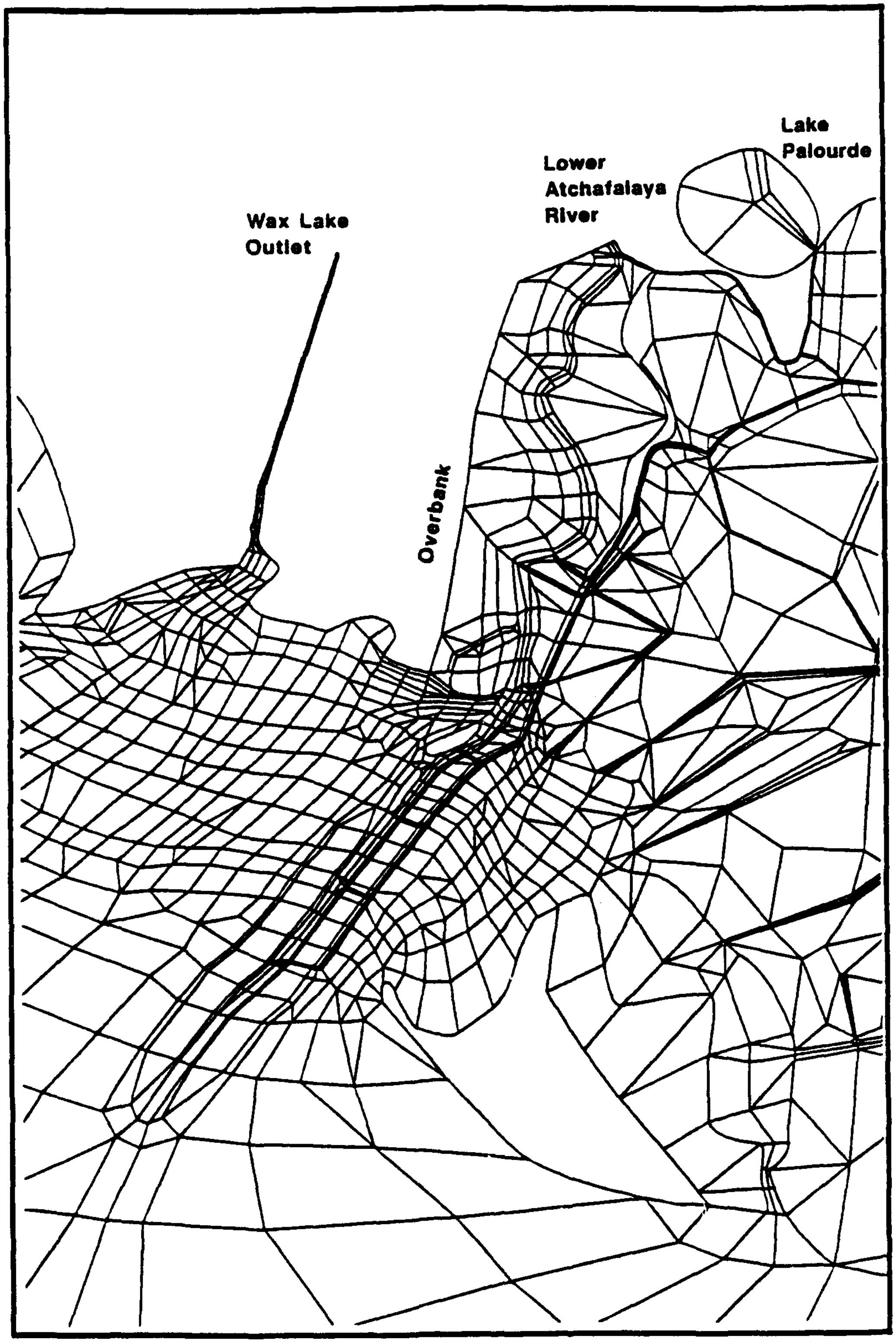


Figure 7. Numerical computational MESH9, used to investigate flood flows in the Atchafalaya Basin

PART II: ALTERNATIVES TESTED

15. The features of each alternative tested within this study are described below. Some of the features were included in the long-term model simulations as they exist/operate in the prototype environment. Other features were turned on/off for purposes of studying their effect on delta evolution and the Terrebonne Marshes.

Features of Each Alternative

Flow control structure on Wax Lake outlet

16. The Wax Lake Outlet (WLO) was constructed in 1942 to improve the capability to pass the Atchafalaya Basin project flood flows to the Gulf of Mexico.

17. The proposed Flow Control Project (F.C.P.) consists of a weir and low-level levee constructed upstream of Wax Lake Outlet to maintain the approximate existing distribution of outlet flows. The existing distribution was described in Report 5 of this series (Thomas et al. 1988). Prototype data collected between 1972 and 1977 at Morgan City on the LAR and Calumet on the WLO determined that during low-flow periods the flow distribution for LAR and WLO was 60 and 40 percent, respectively. As the water discharge increased to 300,000 cfs, the prototype distribution became 65 and 35 percent. The maximum recorded water discharge for this time period (965,000 cfs), resulted in a prototype distribution of 73 and 27 percent. Using these data, the percentage of flow distribution for the LAR and WLO for each discharge event run with the F.C.P. is listed in Table 3.

Table 3

Flow Distribution determined by the WLO F.C.P.

Total Discharge (cfs)	Percent of Flow Distribution LAR	WLO
570,000	70	30
330,000	65	35
150,000	63	37
78,000	60	40

18. The no WLO Flow Control Project ('NO PROJECT') alternative would be to let nature determine the flow distribution between the LAR and WLO as the delta evolved. The flow split degenerated to a 50/50 distribution by year 50.

Avoca Island levee extension

19. In the early 1950's the existing 13-mile Avoca Island Levee was built south of Morgan City to protect the area east of the city from backwater flooding from the LAR. Active delta growth in the Atchafalaya Bay has resulted in the elongation of the river's course and a rise in the water-surface elevation at the end of the levee. In 1981, the USACE proposed a 14,000-foot levee extension to Deer Island to continue backwater flood protection east of the floodway. Figure 8 shows the levee with the proposed Deer Island extension. The purpose of the levee extension alternative testing was to address the concern that the extension would substantially decrease the nourishing sediment presently supplied by the river into the marsh and cause further marsh deterioration.

20. The Avoca Levee Deer Island extension test did not allow fresh water to be diverted laterally into the marsh through the levee. The existing Avoca Island Cutoff to the LAR was sealed, and the test simulated a new 'Deer Island Cutoff' connecting the LAR around the extended levee and merging into the existing cutoff on the east side of the levee. The testing of the Deer Island extension assumed that the levee was extended for all 50 years of simulation.

Dredged Material Placement

21. Half of the alternative plans incorporated dredged material placement. The plans which did maintain the LAR navigation channel but did not incorporate dredge material placement along side the canal, simply placed the dredged material out of the domain of the model. Disposal zones were symmetrically positioned on either side of the LAR navigation canal. Initially the disposal zones were 3000 ft wide and extended from near the coastline to Pt au Fer. As the delta evolved to year 30, the disposal zones were widened to 6000 ft and lengthened to Bar Reach 2. Figure 9 (part a and b) shows the configuration of the disposal zones used in MESH7 and MESH8, respectively. The disposal zones were considered full when their elevation reached +2.5 ft NGVD.

Navigation channel maintenance

22. Most of the alternative plans incorporated maintaining the

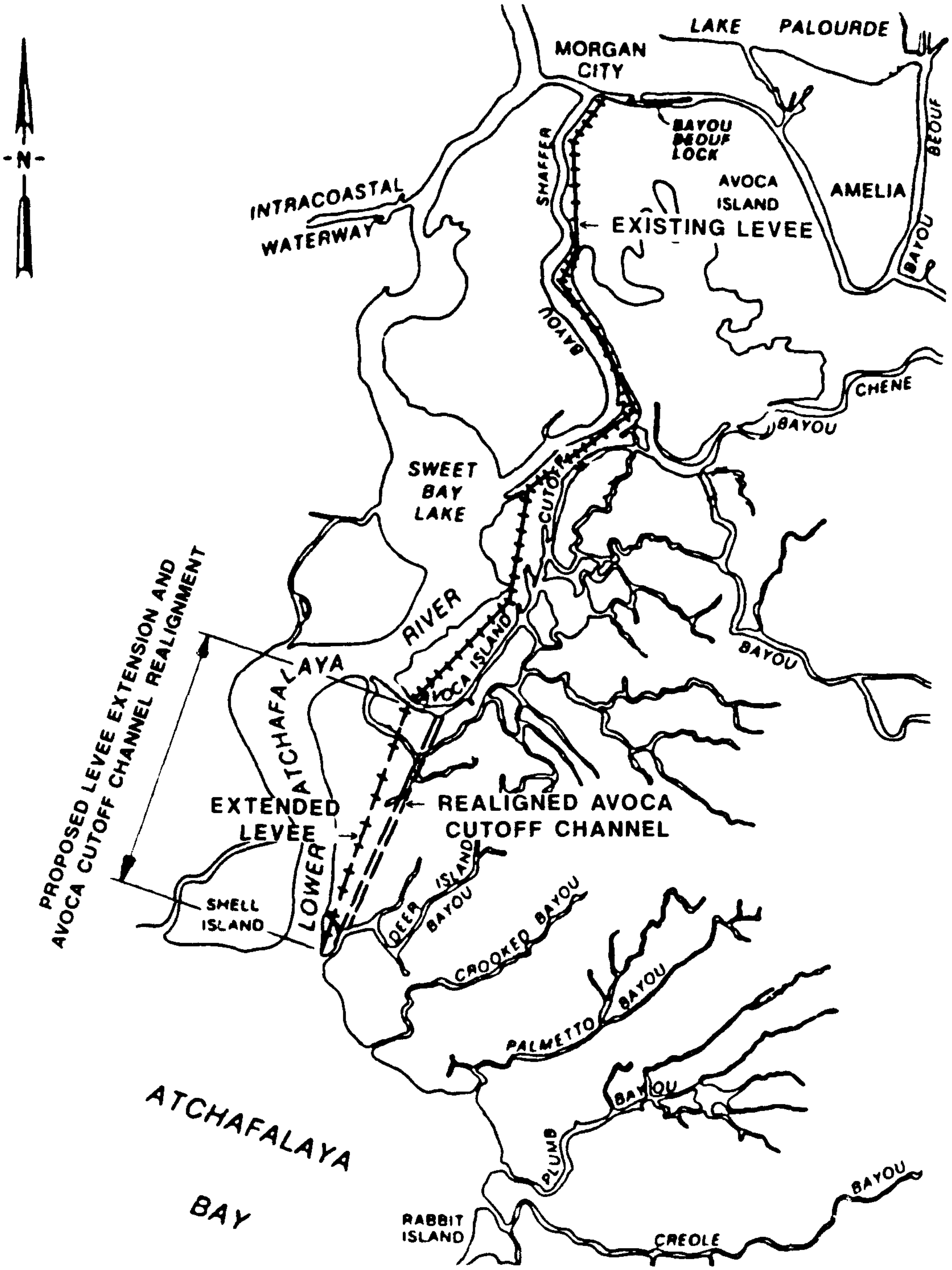
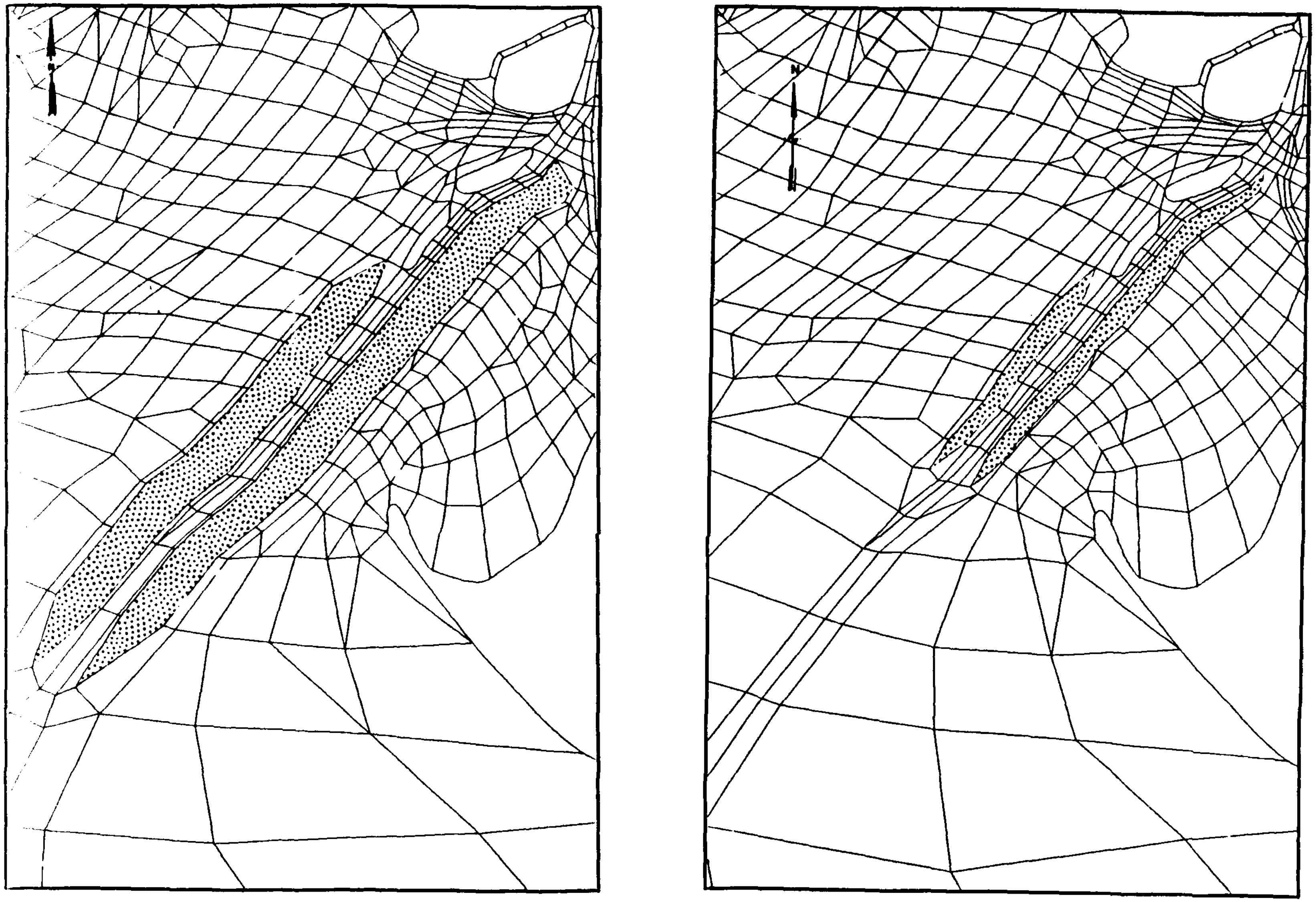


Figure 8. Levee extension plan



a. Year 0-15 disposal zones

b. Year 30-50 disposal zones

Figure 9. Dredge material disposal zones for MESH7 and MESH8, respectively

navigability of the Lower Atchafalaya River. The degree of 'numerical dredging maintenance' for future years in the LAR channel was defined to be that required to maintain equivalent year 0 depths. Alternate plans G and H also permitted the channel to deepen by erosion predicted by the sediment model.

Bayou Boeuf Lock operations

23. The Bayou Boeuf Lock is located near Amelia, LA, and provides for navigation in Bayou Boeuf through the East Atchafalaya Basin Protection Levee (Avoca Island Levee). The lock is 1,156 ft long, has a clear width of 75 ft, and a sill elevation of minus 13.8 ft NGVD. Current operational procedures are to close the gates of the lock when the difference between the west gage and the east gage exceeds 0.5 ft. Typical flow is from west to east; however, there have been some instances where the lock has remained open with flow from east to west.

24. Most of the alternatives tested with the numerical model had the Bayou Boeuf Lock open for the low discharge events and closed for the discharge events above 300,000 cfs (reference Table 4). However, alternate plans G and H each had the lock closed for all discharge events associated with years 30-50.

Project flood condition

25. The project flood flow in the Atchafalaya Basin was simulated in the numerical model in a steady-state fashion. The combined discharge of 1.5 million cfs for the LAR and WLO was simulated for the following alternatives with a year 0 delta and for a year 50 delta:

Existing Avoca Island Levee and mean Gulf level
Existing Avoca Island Levee and Gulf level 5 ft above mean
Extended Levee with mean Gulf level
Extended Levee with Gulf level 5 ft above mean

The distribution of flow between the LAR and WLO was 70 and 30 percent, respectively.

Selected Plans

26. The plan alternatives tested are presented in Table 4 below. Plans B, P, C, X and Y did not take into account dredge material placement, and will be used to compare the fully 2-D FE technique with previous work; such as the Quasi-2D (Thomas et al. 1988) and the regression/extrapolation results (Letter, 1982). Plan D is considered to be the most representative

Table 4

Summary of Production Runs/Alternatives

Plan ID	Channel Maint	Levee Ext	WLO F.C.P.	Dredge Disp Placement	B.Boeuf Lock
B	X	0	0	0	*
P	X	2	0	0	*
C	0	0	0	0	*
X	X	0	X	0	*
Y	X	2	X	0	*
D	X	0	X	X	*
E	X	2	X	X	*
F	X	0	0	X	*
H(30-50)	X+Er	0	X	X	Closed
G(30-50)	X+Er	2	X	X	Closed

Where X - Feature included
0 - Feature not included
Er - Erosion of navigation channel permitted
2 - Levee extended to Reach #2 at Deer Island
* - Bayou Boeuf Lock open for low discharges and closed for discharges above ~300,000 cfs
(30-50) - Applicable only for years 30 through 50

condition to describe the BASE year 0-15 condition (do nothing except maintain navigation channels) and was presented in detail in Report 11 (Donnell, Letter, and Teeter 1991). Plan D will be used as the BASE condition with which plans E, F, G, and H will be compared. Plans G and H are considered to be the most representative alternative for the future (years 30-50). In addition the project flood flow for the Atchafalaya Basin was studied with the 50-year bathymetry predicted from plans D and E.

27. A full 50 year simulation involved approximately 215 batch computer job submissions of the TABS-2 numerical models and pre- and post-processing programs on the Cyber-205 super computer.

PART III: HYDRODYNAMIC RESULTS COMPARED TO BASE CONDITION/PROJECTIONS

Circulation Patterns

28. Plan D, the condition most representative of the status quo at year 0, is designated as the BASE run to which the other plans will be compared. The vector plots presented in this section each represent the residual (net) velocity patterns integrated over a 25 hour tidal cycle. The vector scale in the upper right hand corner provides a reference for the magnitude of the velocity being represented. A vector with a solid shaded head indicates that the current speed exceeds 1.0 fps. Although results were available at the end of each extrapolation period (years 0, 15, 30, and 50), the plates show only the beginning and end of the long-term delta evolution (years 0 and 50). Note that areas of the system will show as land only if they are dry (water depth was insufficient to sustain a significant flow) during the entire tidal cycle.

PLAN D

29. Plan D (BASE) was a simulation of long-term delta evolution with the LAR channel maintenance, the existing Avoca Island Levee, the WLO flow control project (F.C.P.), dredge disposal placement, and with the Bayou Boeuf Lock open only for event numbers 5, 6, and 7 (Table 2 and Table 4). Plates 1 through 10 present the circulation patterns for the Atchafalaya Bay extrapolation area for all events at the end of extrapolation periods for years 0 and 50. There is a significant diversion of flow toward Fourleague Bay at all discharges at year 50 compared to year 0 for Plan D (BASE). In addition, the flow through the Terrebonne Marshes has come out of its banks by year 50 due to backwater flooding for the 330,000 and 570,000 cfs conditions.

PLAN E

30. Plan E is the same as Plan D (BASE) except that the Avoca Island Levee was extended to Deer Island. Plates 11 through 20 present the circulation patterns for the Atchafalaya Bay extrapolation area for all events at the end of the year 50 extrapolation period. For the evaluation of the effects of the extended levee on circulation patterns, Plates 1 through 10 compare with Plates 11 through 20. At year 0 there are only minor differences between Plan E circulation patterns and the Plan D (BASE) patterns in the local area

around the extended levee. For year 50, Plan E shows an even greater flow shift toward Fourleague Bay, and greater wetted area in Terrebonne Marsh.

PLAN F

31. Plan F, the 'NO PROJECT' simulation, is the same as Plan D (BASE) except that the Wax Lake Outlet flow control project was deactivated beginning at year 15. The omission of the F.C.P. allows the distribution of flow between LAR and WLO to vary between 70/30 percent for high discharge events and 50/50 percent for low discharge events. Plates 21 through 25 present the circulation patterns for the Atchafalaya Bay extrapolation area for all events at the end of the year 50 extrapolation period. For the evaluation of the effects of deactivating the F.C.P. Plates 6 through 10 compare with Plates 21 through 25. The change in the LAR/WLO flow split for Plan F at year 50 is evident in the flow patterns, with the results being greater channelization in the WLO delta.

PLAN G

32. Plan G is the same as Plan E through year 30. Plan G differs from Plan E in that in years 30 and 50 it allows the LAR and WLO channels to erode deeper than the Year 0 bathymetry and the Bayou Boeuf lock is closed for all discharges. Plates 26 through 30 present the circulation patterns for the Atchafalaya Bay extrapolation area for all events at the end of the year 50 extrapolation period. For the evaluation of the effects of channel erosion and lock strategy with the Avoca levee extended to Reach 2 at Deer Island, Plates 31 through 35 compare with Plates 16 through 20. There is very little difference between the Plan G and Plan E circulation patterns.

PLAN H

33. Plan H is the same as Plan D (BASE) through year 30. Plan H differs from Plan D (BASE) in that years 30 and 50 allow the LAR and WLO channels to erode deeper than the Year 0 bathymetry and the Bayou Boeuf lock remained closed for all discharges. Plates 31 through 35 present the circulation patterns for the Atchafalaya Bay extrapolation area for all events at the end of the year 50 extrapolation period. For the evaluation of the effects of channel erosion and lock strategy with the existing levee configuration, Plates 26 through 30 compare with Plates 6 through 10. There are very little differences between Plan H and Plan D (BASE) circulation patterns.

Water-Surface Elevation Changes

34. Tables 5, 6, and 7 present the change of water-surface elevation for the highest discharge event (570,000 cfs) at various locations throughout the computational network from year 0 to each extrapolated year. Tables 5 and 6 present the changes in water-surface elevation for the highest discharge event (570,000 cfs) at various locations through the computational network for Plans D, E, G, and H for years 15, 30, and 50 relative to Plan D year 0. Table 7 summarizes the changes between year 50 and year 0 for all plans. For instance, the values for Plan D (BASE), year 50 is based upon the change in the water-surface elevation relative to Plan D, year 0, and similarly the value for Plan E, year 50 is relative to Plan D, year 0. The locations are presented in Figure 10. Each value was determined by interpolating tidally averaged values from a cluster of computational points centered around the area of interest. This technique removes tidal fluctuations and avoids any potential numerical oscillations.

35. For all plans there are dramatic increases in water-surface elevations by year 50. At year 0 Plan E provided flood control benefits at all of the locations presented, with maximum reduction of 1.7 ft in elevation behind the levee. By year 50, Plan E had lowered flood stages in Terrebonne Marshes relative to Plan D (BASE) by up to 1.1 ft, but elevations were raised within Atchafalaya Bay by as much as 1.5 ft. As expected, Plan F raised flood levels at Wax Lake Outlet and the western portion of Atchafalaya Bay, while lowering levels at Lower Atchafalaya River and in Terrebonne Marshes. Plan G relative to Plan H provides the most probable scenario for future conditions so as to evaluate the impact of the levee extension at year 50. This again shows significant flood protection for the Terrebonne marshes.

36. The project flood for the Atchafalaya Basin (1.5 million cfs combined discharge for LAR and WLO with a 70-30% flow split, respectively) was tested for 8 combinations of delta development, Avoca Island levee reaches, and Gulf of Mexico water levels. The project flood tests were conducted in a steady state RMA-2 simulation with a 25,000 cfs inflow at Lake Palourde. The configurations for each test are identified in Table 8.

37. The changes in water-surface elevation for the project flood of the Atchafalaya Basin test configurations are given in Table 9. Showing the effects of the levee extension. The values presented are the difference

Table 5

Change in Water-Surface Elevation (ft) For the 570,000 cfs Event (D & E) Relative to Plan D (BASE) Year 0

Location	Existing Levee**			Levee Extended**			
	D-15	D-30	D-50	E-0	E-15	E-30	E-50
1 Atchafalaya Bay (West)	-0.03	0.15	2.86	0.00	-0.03	0.15	3.19
2 Atchafalaya Bay (Central)	-0.16	0.12	4.05	0.00	-0.16	0.21	5.41
3 Atchafalaya Bay (East)	1.91	3.34	5.29	-0.20	1.81	3.03	6.79
4 LAR at Coastline	3.13	4.00	5.14	0.00	3.04	4.21	6.77
5 WLO at Coastline	0.91	1.82	2.60	0.00	0.93	1.86	3.08
6 Fourleague Bay (North)	1.73	2.42	4.62	-0.20	1.64	2.53	4.15
7 Fourleague Bay (South)	1.60	1.46	4.08	-0.30	1.52	2.01	3.52
8 Tip of Existing Levee *	2.07	2.65	3.07	-1.70	0.41	1.12	2.04
9 Tip of Extended Levee	2.82	3.60	4.38	-0.06	2.57	3.38	5.49
10 Bayou Boeuf at Amelia	2.35	2.93	5.06	-1.24	0.36	0.72	4.82
11 GIWW near Houma	2.29	2.86	4.10	-0.12	1.09	1.93	4.04
12 Lost Lake	1.41	1.64	3.87	-0.07	1.39	1.68	3.34
13 Bayou Penchant at Chene	1.54	1.84	2.05	-1.69	0.31	0.71	1.64
14 Lake Palourde	2.74	3.48	5.65	-1.20	0.40	0.85	5.44

* The location is east of the levee in the Avoca Island Cutoff.
** Column headings indicate Plan number and year. D-15 means Year 15 results for Plan D.

Table 6

Change in Water-Surface Elevation (ft) For the 570,000 cfs Event (G & H) Relative to Plan D (BASE) Year 0

Location	Existing Levee**			Levee Extended**			
	D-15	H-30	H-50	E-0	E-15	G-30	G-50
1 Atchafalaya Bay (West)	-0.03	0.15	2.55	0.00	-0.03	0.15	2.56
2 Atchafalaya Bay (Central)	-0.16	0.12	5.01	0.00	-0.16	0.21	4.97
3 Atchafalaya Bay (East)	1.91	3.34	6.34	-0.20	1.81	3.03	6.17
4 LAR at Coastline	3.13	4.00	6.22	0.00	3.04	4.21	5.93
5 WLO at Coastline	0.91	1.82	1.78	0.00	0.93	1.86	5.05
6 Fourleague Bay (North)	1.73	2.42	4.84	-0.20	1.64	2.53	3.47
7 Fourleague Bay (South)	1.60	1.46	4.23	-0.30	1.52	2.04	2.89
8 Tip of Existing Levee *	2.07	2.65	3.84	-1.70	0.41	1.12	1.26
9 Tip of Extended Levee	2.82	3.60	5.35	-0.06	2.57	3.38	4.76
10 Bayou Boeuf at Amelia	2.35	2.93	3.78	-1.24	0.36	0.72	2.18
11 GIWW near Houma	2.29	2.86	4.92	-0.12	1.09	1.93	2.97
12 Lost Lake	1.41	1.64	4.14	-0.07	1.39	1.68	2.46
13 Bayou Penchant at Chene	1.54	1.84	2.87	-1.69	0.31	0.71	0.79
14 Lake Palourde	2.74	3.48	3.87	-1.20	0.40	0.85	2.35

* The location is east of the levee in the Avoca Island Cutoff.
** Column headings indicate Plan number and year. D-15 means Year 15 results for Plan D.

Table 7

Change in Water-Surface Elevation (ft) Year 50 Relative to Plan D (BASE) Year 0 For the 570,000 cfs Event

Location	D-50	E-50	F-50	G-50	H-50
1 Atchafalaya Bay (West)	2.86	3.19	-	2.56	2.55
2 Atchafalaya Bay (Central)	4.05	5.41	-	4.97	5.01
3 Atchafalaya Bay (East)	5.29	6.79	-	6.17	6.34
4 LAR at Coastline	5.14	6.77	3.47	5.93	6.22
5 WLO at Coastline	2.60	3.08	3.08	5.05	1.78
6 Fourleague Bay (North)	4.62	4.15	-	3.47	4.84
7 Fourleague Bay (South)	4.08	3.52	-	2.89	4.23
8 Tip of Existing Levee *	3.07	2.04	1.36	1.26	3.84
9 Tip of Extended Levee	4.38	5.49	2.68	4.76	5.35
10 Bayou Boeuf at Amelia	5.06	4.82	1.12	2.18	3.78
11 GIWW near Houma	4.10	4.04	3.00	2.97	4.92
12 Lost Lake	3.87	3.34	-	2.46	4.14
13 Bayou Penchant at Chene	2.05	1.64	0.75	0.79	2.87
14 Lake Palourde	5.65	5.44	-	2.35	3.87

Where - indicates that data were not obtained, and '*' indicates that the location is east of the levee in the Avoca Island Cutoff.

Table 8

Atchafalaya Basin Project Flood Test Configurations

Test	Atchafalaya Bay Bathymetric Year	Gulf Level (ft above NGVD)	Avoca Island Levee Reach
D - 0 - 0	1980	0	0
E - 0 - 0	1980	0	2
D -50 - 0	2030	0	0
E -50 - 0	2030	0	2
D - 0 - 5	1980	5	0
E - 0 - 5	1980	5	2
D -50 - 5	2030	5	0
E -50 - 5	2030	5	2

between the Reach 2 extended levee and the original levee for the same set of conditions. Table 10 provides the effects of the 50-year delta growth prediction on the change of water level. For instance, the value for Plan D, year 50, mean Gulf, is based on the change in the water-surface elevation relative to Plan D, year 0, mean Gulf and similarly the value for Plan E, year 50,

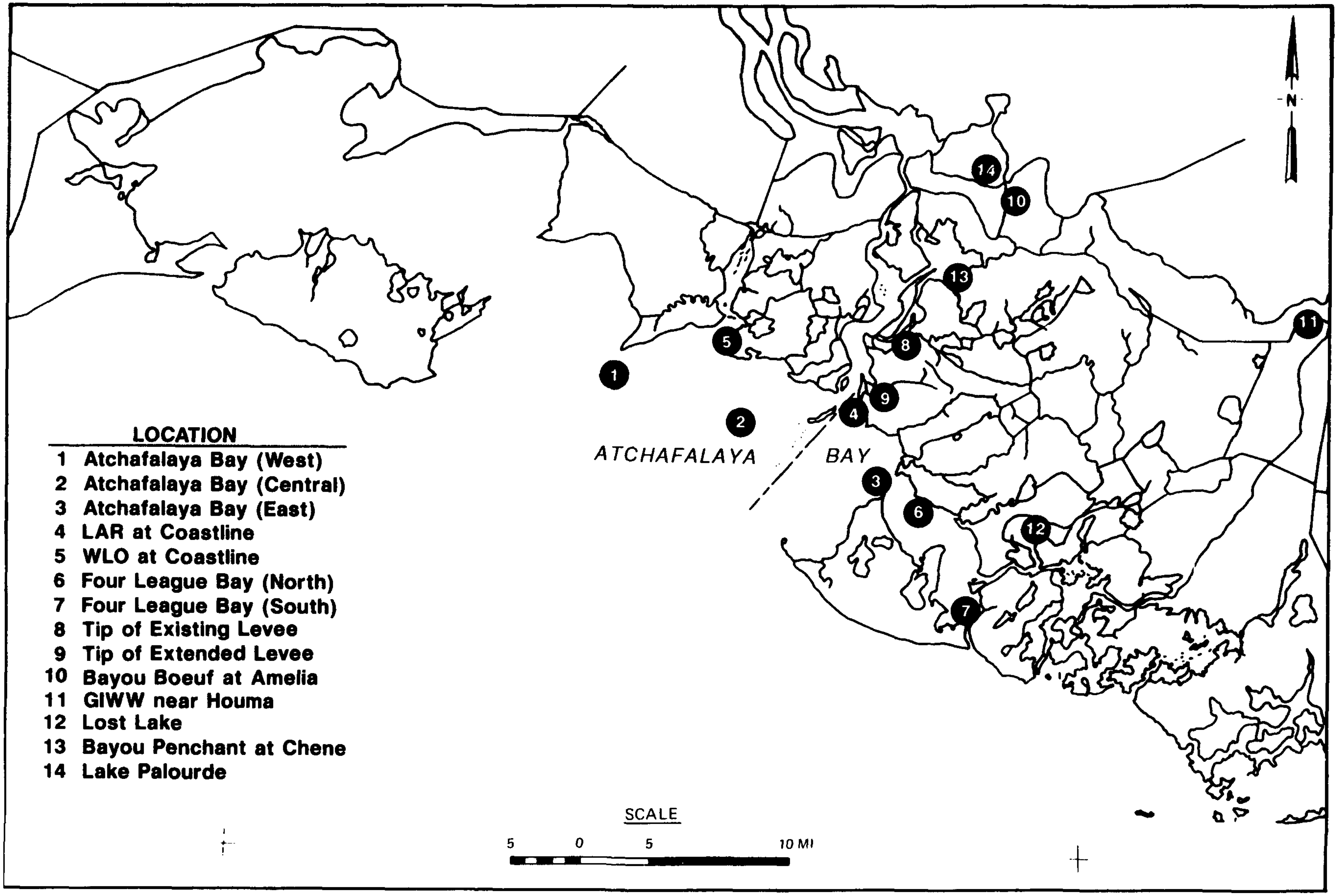


Figure 10. Areas of interest

Table 9

Change in Water-Surface Elevation (ft) Extended Levee (Plan E) Relative to Existing Levee (Plan D) for the Given Year For the Atchafalaya Basin Project Flood Condition

Location	E-0-0 vs D-0-0	E-50-0 vs D-50-0	E-0-5 vs D-0-5	E-50-5* vs D-50-5
8 Tip of Existing Levee**	-4.09	-2.68	-3.46	-2.58
9 Tip of Extended Levee	- .27	- .07	- .29	- .11
10 Bayou Boeuf at Amelia	- .20	- .79	- .67	- .69
11 GIWW near Houma	-1.15	-1.28	- .39	- .99
13 Bayou Penchant at Chene	-2.22	-1.60	-1.76	-1.47

* Column headings indicate Plan number-year-Gulf level above mean Gulf.
** The location is east of the levee in the Avoca Island Cutoff.

Table 10

Change in Water-Surface Elevation (ft) Year 50 Delta Relative to Year 0 Delta For the Atchafalaya Basin Project Flood Condition

Location	D-50-0 vs D- 0-0	E-50-0 vs E- 0-0	D-50-5 vs D- 0-5	E-50-5* vs E- 0-5
8 Tip of Existing Levee**	4.1	5.5	3.6	4.5
9 Tip of Extended Levee	6.6	6.8	5.6	5.7
10 Bayou Boeuf at Amelia	1.6	1.0	1.4	1.4
11 GIWW near Houma	4.9	4.7	3.0	2.4
13 Bayou Penchant at Chene	3.8	4.9	3.2	3.5

* Column headings indicate Plan number-year-Gulf level above mean Gulf.
** The location is east of the levee in the Avoca Island Cutoff.

5 feet above mean Gulf is relative to Plan E, year 0, 5 feet above mean Gulf. The locations were previously presented in Figure 9.

38. As was the case for the 570,000 cfs flow, Plan E provides significant flood protection to the Terrebonne Marshes for the project flood. However, as the delta evolves, the degree of protection diminishes somewhat. This is apparently the result of increased backwater effects from the delta itself.

PART IV: SEDIMENTATION RESULTS COMPARED TO EXISTING CONDITION/PROJECTIONS

39. Several methods will be presented in this section to examine the results obtained from the long-term delta evolution simulations.

Delta Evolution Predictions

40. Plan views of the predicted delta at the end of each extrapolation period are presented for each of the alternatives tested. The BASE, existing condition (year 0) bathymetry is presented in Plate 36. Predicted extrapolated bathymetry are available at the end of years 15, 30 and 50. For Plan D, the predicted bathymetry at years 15, 30, and 50 are provided in Plates 37 through 39. Plan E year 0 is the same as Plan D year 0 except for the Avoca Island levee extension to Deer Island (Reach #2). Plan E predicted bathymetry for years 15, 30, and 50 are provided in Plates 40 through 42. Predicted bathymetry for Plan F, years 30 and 50 are provided in Plates 43 and 44. Note that Plan F year 15 is the same as Plan D year 15. Plan G year 50 predicted bathymetry is shown on Plate 45. Plan H year 50 predicted bathymetry is shown on Plate 46. Plan G and H are the same as E and D, respectively, through year 30.

41. Of note is the ever increasing subaerial (elevation of NGVD or greater) delta at each extrapolation year. Also note that the delta formation at year 15 beyond Pt Au Fer Island has eroded by year 30. However, by year 50 the delta has evolved beyond Pt. Au Fer for all plans. The highest rate of subaerial emergence occurs between years 30 and 50 for all plans.

42. At year 50, there are insignificant differences in the evolved delta between Plans D (BASE) and H, and between Plans E and G. The differences between the existing levee (Plans D and H) and the extended levee (Plans E and G) are that the extended levee results have slightly greater subaerial extent in LAR delta compared to WLO delta. The overall result is about 8% greater subaerial delta by year 50 with the levee extended to Reach 2 than with existing levee conditions.

43. Plan F results in a much smaller delta compared with all of the other plans. The year 50 subaerial delta is 18 percent smaller than the Plan D delta at year 50. This reduction is in part attributed to loss of

material beyond the domain of the long-term extrapolation window (Figure 3) into the western bays by the increasing flow dominance of WLO with Plan F.

44. The 50-year delta volume and subaerial extent are summarized in Table 11 for most of the plans tested (see Table 3). These are all associated with the verification window (Figure 3). Plans X, Y, and C all had smaller deltas than any of the plans previously discussed primarily because dredged material was not placed adjacent to the channel but was removed from the system. Plan C had no channel maintenance at all and represents the delta evolution with no further activities of man in the system.

Table 11

Summary of Delta Evolution for Production Runs Year 50

	Volume of Sediment (cubic km)* Above elevation (ft) plane			Subaerial Area*	
Plan	-6	-3	0	(sq km)	sq mi
X	1.045	0.410	0.095	204	79
Y	0.912	0.319	0.052	145	56
C	0.924	0.340	0.057	159	61
D	1.141	0.499	0.127	279	108
E	1.246	0.522	0.141	306	118
F	1.064	0.444	0.099	237	92
G	1.253	0.554	0.141	306	118
H	1.138	0.498	0.126	278	107

* Within the verification window (see Figure 3).

45. Table 12 provides a comparison of the predicted volume of the delta evolution for the alternatives which incorporated dredged material placement. The sediment volumes presented were calculated based upon the larger extrapolation window, as shown in Figure 3. Plate 47 compares the subaerial land at year 50 for the various alternatives.

Maintenance Dredging of the Navigation Channel

46. Plan comparisons of total depositional volume in the Lower Atchafalaya River navigation channel are given in Table 13. Each of the alternative

Table 12

Predicted Volume of Sediment (cubic kilometers)

Above the Given Elevation Plane

Plan-Year	Volume of Sediment (cubic km)* Above elevation (ft) plane -6	-3	0	Subaerial Area* (sq km)	sq mi
D - 0	0.363	0.083	0.007	22	8
D - 15	0.523	0.138	0.016	48	18
D - 30	0.847	0.299	0.059	141	55
D - 50	1.464	0.634	0.158	346	134
E - 15	0.509	0.130	0.013	43	16
E - 30	0.881	0.319	0.062	151	58
E - 50	1.566	0.683	0.171	374	144
F - 30	0.850	0.293	0.055	137	53
F - 50	1.350	0.548	0.119	283	109
G - 50	1.540	0.673	0.169	369	143
H - 50	1.436	0.622	0.156	340	131

* Within the long-term delta evolution window (see Figure 3).

Table 13

Change in the LAR channel Total Depositional Volume

Relative to Plan D - Year 15

Plan/Year	LAR Volume Factor
D - 15	1.0
D - 30	3.3
D - 50	2.6
E - 15	.9
E - 30	3.6
E - 50	2.7
F - 30	3.0
F - 50	1.8
G - 50	2.8
H - 50	2.6

plan volumes are given as a ratio relative to the BASE (existing condition, Plan D), predicted LAR channel deposition for year 15. Note that all plans indicate peak dredging requirement near year 30 with a subsequent taper in volume at year 50. The taper appears to be caused by channelization.

Sedimentation Changes from Years 0 to 50 Within the Terrebonne Marshes

47. Although the delta evolution was not predicted within the Terrebonne Marshes, one of the purposes of the study was to estimate the impact of the delta evolution on sedimentation rates within the Terrebonne Marshes. Figure 11 indicates the zone demarcation for the sedimentation distribution computation. Program SEDDIST (described in Report 11, Donnell, Letter, Teeter 1991) was designed to examine the concentration and bed change final results file of a STUDH event simulation and calculate the sedimentation distribution for given zones defining the areas of interest. The joint probability statistical method was used to combine the sedimentation rates within each zone. The change in the deposition rate of sediment within each designated zone for Plans D, E, F, G and H over the fifty year simulation is given in Table 14. Table 14 is interpreted as the difference in the rate of sedimentation from a given plan, given year, versus the sedimentation rate for Plan D, year 0. Note that the Terrebonne Marshes sedimentation is generally reduced as a result of extending the levee with the 1980 bathymetric condition (Plan E year 0). Detailed net gain or loss of sediment within each zone (after subsidence) are provided for Plan H and G (the most probable future scenarios) in Table 15. Subsidence calculations are provided in Appendix A of Report 11 of this series (Donnell, Letter, and Teeter, 1991) and varied spatially as shown previously in Figure 4.

Table 14

Change in Rate of Deposition by Zone (cm/yr) Relative to Existing Condition (Plan D Year 0)

ZONE	E-Year 0	D-Year 50	E-Year 50	F-Year 50	G-Year 50	H-Year 50
1	-0.6	4.9	3.3	1.0	2.9	5.2
2	-1.2	0.7	-0.4	-0.7	-1.2	-1.0
3	0.0	1.3	3.6	1.3	1.8	1.0
4	-0.7	0.0	0.4	-0.8	-0.2	0.6
5	-0.2	0.0	0.3	1.5	0.3	0.1
6	0.0	4.8	8.5	0.1	8.7	11.5
7	-1.2	5.1	4.1	6.1	4.4	4.6

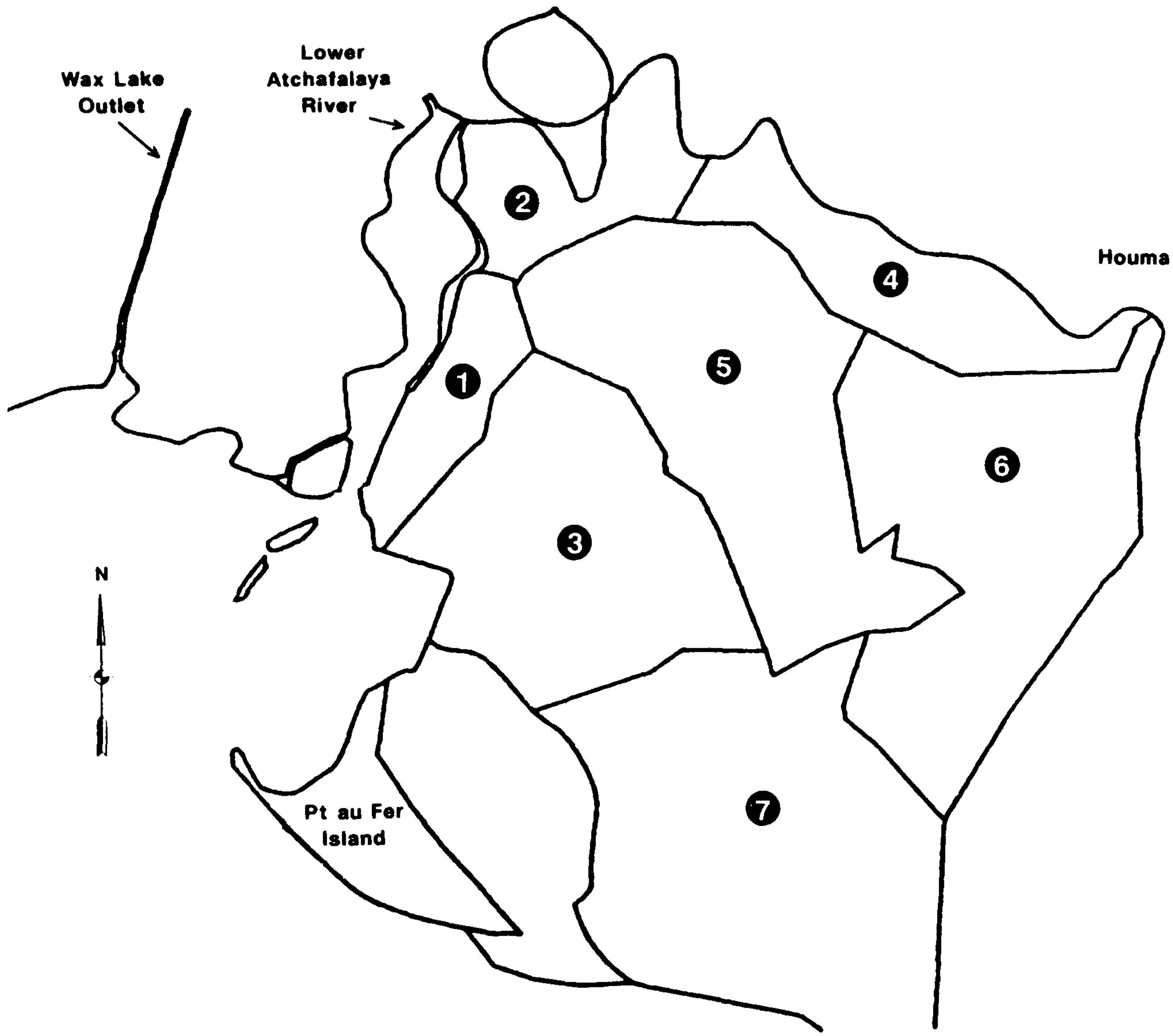


Figure 11. Sedimentation distribution zones for Terrebonne Marshes

Table 15

Rate of Sedimentation (after subsidence) by Zone

	Existing Levee Net Deposition (cm/yr)		Extended Levee Net Deposition (cm/yr)	
ZONE	D-Year 0	H-Year 50	E-Year 0	G-Year 50
1	0.7	5.9	0.1	3.7
2	2.2	1.2	1.1	1.1
3	-1.3	-0.2	-1.3	0.5
4	0.1	0.7	-0.7	-0.1
5	-0.9	-0.8	-1.1	-0.7
6	-0.6	10.9	-0.5	8.1
7	0.1	4.7	-1.1	4.4

Effect of delta evolution

48. When compared to year 0 sedimentation rates (Tables 14 and 15), most plans tested showed a net increase in deposition rates within the Terrebonne Marshes as the delta evolved to year 50. The only exceptions were zone 2, located just below the Bayou Boeuf Lock and zone 4, located north of the Gulf intracoastal waterway.

Effect of levee extension

49. The general effect on the Terrebonne Marshes of the levee extension was mixed. At year 0, every zone had either no change or a reduced sedimentation rate (Table 15, Plans E-0 vs D-0). The effect at year 50 with the Bayou Boeuf Lock open at low flows (Table 14, Plans E-50 vs D-50) was a reduction just east of the levee (zones 1 and 2) and in the southeast zone 7, but with increased deposition in the central and eastern zones. With the Bayou Boeuf Lock closed for low flows (Table 15, Plans G-50 vs H-50) after year 30, the supply of sediment to the Terrebonne Marshes is further restricted and a reduction in deposition is observed in all zones except 3 and 5 which are located in the center of the marsh.

Effect of closing Bayou Boeuf Lock

50. The effect of the closing of the Bayou Boeuf Lock after year 30 for the existing levee (Table 14, D-50 vs H-50) was reduced sedimentation in zones 2, 3, and 7. The effect of the closure for the extended levee (Table 14, E-50 vs G-50) was to reduce sedimentation in zones 1 through 4. The effect of the closure seems to be immediately east and upstream of the

levee with some additional impact to the southeast by affecting the supply through Fourleague Bay.

Effect of altered flow diversion

51. The change in flow split distribution between WLO and LAR (Table 14, D-50 vs F-50) by year 50 resulted in reduced sedimentation in the majority of zones associated with water and sediment supply from LAR (zones 1, 2, 4, and 6) and an increase in zones 5 and 7, which may get some indirect sediment supply via Fourleague Bay and the Gulf.

PART V: SALINITY RESULTS COMPARED TO EXISTING CONDITION/PROJECTIONS

52. As described in Report 11 of this series, the salinity transport (RMA-4) simulations had an extended time-step using residual currents. The residual currents were calculated from RMA-2 and supplied as the velocity field to RMA-4 with a 25-hour time-step. Salinity modeling was conducted for the lower discharge events for year 0 (1980) and year 50 (2030) only. The discharge events were: 330,000, 150,000, and 78,000 cfs with a mean Gulf level.

53. The year 0 salinity isohalines for each of the three discharge events with the BASE condition (Plan D), are presented in Plates 48 through 50. As expected, the salinity concentrations were lower in the bay and Terrebonne Marshes for the higher inflow conditions.

54. The year 0 salinity isohalines for each of the three discharge events with the plan, extended levee condition (Plan E), are presented in Plates 51 through 53. In comparing the effects of the year 0 BASE (Plan D) versus extended levee condition (Plan E), there was some freshening of the bay and a slight increase in salinity in Terrebonne Marshes. These effects were most evident for the 330,000 cfs case, with minor changes for lower flows.

55. The salinity isohalines for plan D year 50 are presented for each of the three discharge events in Plates 54 through 56. All three discharges exhibited a freshening of the Terrebonne Marshes after 50 years of delta evolution compared to the salinity conditions for plan D, year 0 (Plates 48 through 50), with some slight increase in salinities in the western bays.

56. The salinity isohalines for plan E (the extended levee) year 50 are presented for each of the three discharge events in Plates 57 through 59. The LAR channel was slightly fresher at the low discharge after 50 years of delta evolution with the extended levee compared to the base condition (Plan D year 50), while there was a slight increase in salinity in Fourleague Bay.

57. The salinity isohalines for plan F (existing levee with no WLO flow control) year 50 are presented for each of the three discharge events in Plates 60 through 62. In general the area east of the levee did not have as much fresh water supply and consequently, the salinity concentrations were higher in the Terrebonne Marsh area for plan F as compared to plan D, while there is some freshening in the western bays.

58. The salinity isohalines for plan G (same as plan E except for the closure of Bayou Boeuf Lock from years 30-50) year 50 are presented for each of the three discharge events in Plates 63 through 65. The differences in concentrations were negligible between plans E and G.

59. The salinity isohalines for plan H (same as plan D except for the closure of Bayou Boeuf Lock from years 30-50) year 50 are presented for each of the three discharge events in Plates 66 through 68. The differences were negligible between plans D and H, while the differences between G and H are comparable to the differences between E and D at year 50.

PART VI: CONCLUSIONS

60. The conclusions developed during the presentation of the modeling verification and no-change delta evolution modeling in Report 11 of this series (Donnell, Letter, and Teeter, 1991) were based on Plan D described in this report. Those conclusions are appropriate for the general impacts of the delta evolution and are summarized here:

- a. The modeling tools developed are capable of predicting the delta evolution over both the short term and long term.
- b. These tools can accurately assess the impact of the delta evolution on flood levels, circulation, sedimentation and salinity intrusion.
- c. Under existing conditions the subaerial extent of the delta will dramatically increase to potentially over 100 square miles within the next 50 years.
- d. The evolved deltas will result in significantly higher stages within the entire system.
- e. Circulation will be altered to divert more flow through Four League Bay at all discharges as the delta evolves.
- f. As a results of (d) and (e) above, salinities will be reduced in Terrebonne Marshes.
- g. Dredging requirements may be reduced in the short term, but increase for the long-term. Requirements will peak around year 30 then begin to diminish by year 50.

61. The effects of the BASE (Plan D) and various alternatives studied are discussed below. Primary plan features are the levee extension, dredged material placement, and flow control on the Wax Lake Outlet.

Effect of Delta Evolution

On flood stages

62. The evolved 50-year delta will result in significantly higher flood stages within the entire system. The increases in stage may be as much as 6 ft near the mouths of WLO and LAR, and 5 ft within the Terrebonne Marshes.

On circulation

63. Circulation will be altered to divert more flow through Fourleague Bay at all discharges. This diversion will result from increasing water levels at the upper end of Atchafalaya Bay in response to the reduced hydraulic efficiency of the bay. Flow through the Terrebonne Marshes will increase

as well due to the increased stages and greater inundation.

On salinity intrusion

64. As a result of the delta evolution over the 50-year study period, salinities will be reduced in Terrebonne Marshes by as much as 1 ppt. No significant change in salinities was observed in the western bays or Atchafalaya Bay.

On sedimentation rates in Terrebonne Marshes

65. As the delta evolves, the sedimentation rates within the Terrebonne Marshes will increase on an average of about 3 cm/yr by year 50 relative to year 0 sedimentation rates (Table 15).

On navigation channel maintenance

66. Dredging requirements may be reduced in the short-term, but increase for the long-term to as much as three times present requirements. Requirements will peak around year 30 then begin to diminish.

Effects of Avoca Island Levee Extension

On delta evolution

67. The extended levee results in about 8 percent more subaerial land than the existing levee by year 50. This is apparently the result of the levee extension delivering more sediment to the bay at the expense of Terrebonne Marshes, as evidenced by the reduced deposition rates in the marshes for the extended levee.

On flood stages

68. The primary effect of the levee extension is to provide flood protection to the communities east of the existing levee. Without the levee extension for the 57,000-cfs discharge, the flood stages in the vicinity of Amelia, LA will rise by almost four feet by year 50 with the existing levee. Extending the levee reduces that increase to about two feet. For the project flood flow in the Atchafalaya Basin, there is a comparable level of reduction protection (up to 2.0 ft) with the levee extension.

On circulation

69. At year 0 the response of the circulation patterns to the levee extension is very subtle and only clearly noticeable in the vicinity of the levee itself. The overall flow patterns do not appear to be dramatically

impacted; however, the sedimentation results (below) suggest a reduction in flow to the marshes.

On salinity intrusion

70. There was very little impact on salinities associated with the levee extension. There is a slight freshening of Atchafalaya Bay and increasing of salinity in Terrebonne marshes, but by less than 0.1 ppt in both areas relative to the existing levee tests.

On sedimentation in Terrebonne Marshes

71. The general trend of sedimentation in response to the levee extension at year 0 is a reduction in rates associated with reduced supply from around the tip of the levee (G-50 vs H-50). This trend is repeated at year 50, but with the center of the marshes (zones 3-7) experiencing some localized increase in deposition. However, these impacts are to reduce the general level of the increase in deposition associated with the evolving delta. That is, the overall sedimentation rates will go up with time, but not as much as without the levee extension.

On navigation channel maintenance

72. For the year 0 to 15 year conditions the impact of the levee extension on navigation channel maintenance was small. There could be a slight reduction in requirements (10 percent) due to the additional flow supplied to the bay. However, by year 50, the extended levee may result in a 5 to 10 percent increase in maintenance requirements relative to the existing levee at year 50.

Effect of Wax Lake Outlet Flow Control

On delta evolution

73. The absence of flow control (allowing flow split to range from 70/30 to 50/50 depending on discharge) on Wax Lake Outlet results in a significant reduction (18 percent) in the extent of delta by year 50. In addition, the developing delta had a greater degree of channelization in the western end of Atchafalaya Bay compared to the eastern end of the bay.

On flood stages

74. The shift in flow split also resulted in a shifting of the flood stages, with increased water levels (by 0.4 ft) at WLO coastline and decreased levels on the eastern end of the bay and throughout the Terrebonne Marshes.

On circulation

75. The circulation patterns for year 50 were noticeably altered to favor the WLO side of the bay to carry greater flow, with increased channelization in the evolving delta as a result.

On salinity intrusion

76. The salinities at year 50 for the lower flow rate were increased in Terrebonne marshes with Plan F and reduced in Atchafalaya Bay and adjacent waters.

On sedimentation in Terrebonne Marshes

77. The sedimentation rates for year 50 in the Terrebonne Marshes were generally reduced with the Plan F loss of flow and sediment supply from the LAR to the eastern portion of the system.

On navigation channel maintenance

78. The estimated channel maintenance with the loss of flow control (Plan F) was 10 percent lower than estimated for the controlled flow condition (Plan D) for year 30 and was 30 percent lower by year 50, as a result of the reduced sediment supply from the LAR.

Effect of Dredged Material Placement

79. The placement of dredged material adjacent the navigation channel resulted in a dramatic increase in the extent of delta evolution. The area of subaerial land increased by approximately forty percent with the placement. However, the elimination of all dredging activity could result in a 20 percent reduction in the delta area.

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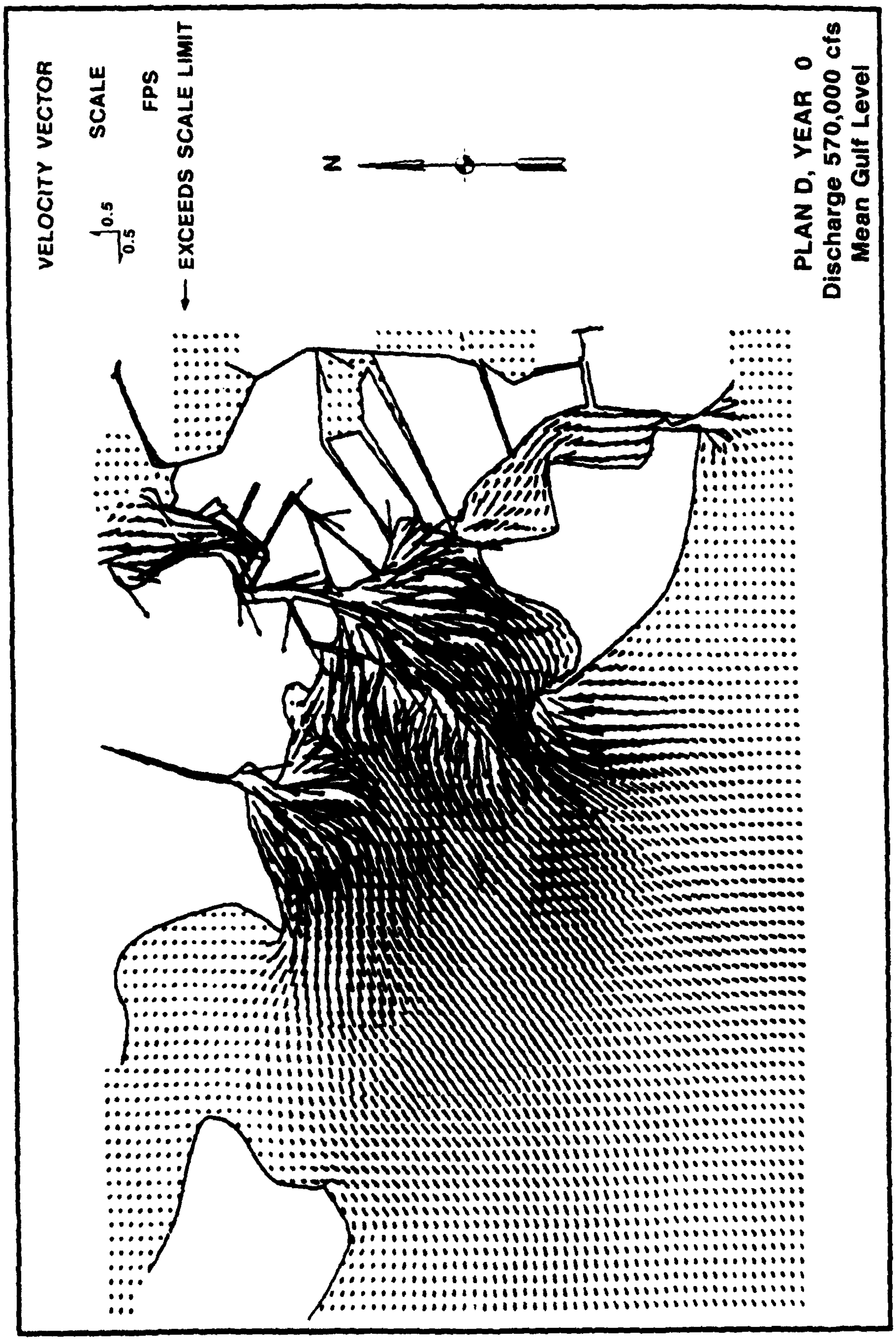
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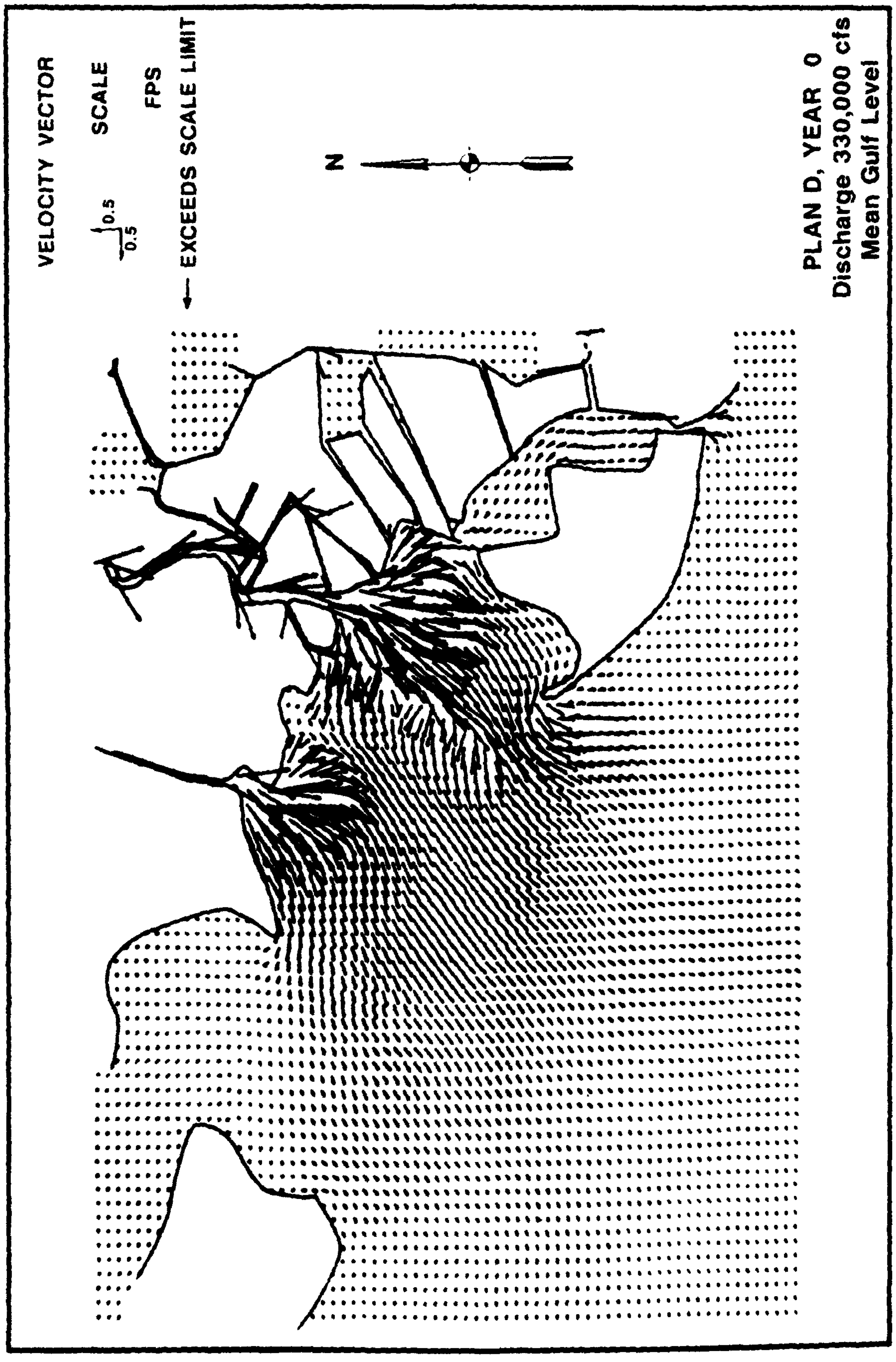
Discharge 570,000 cfs
Mean Gulf Level

PLATE 1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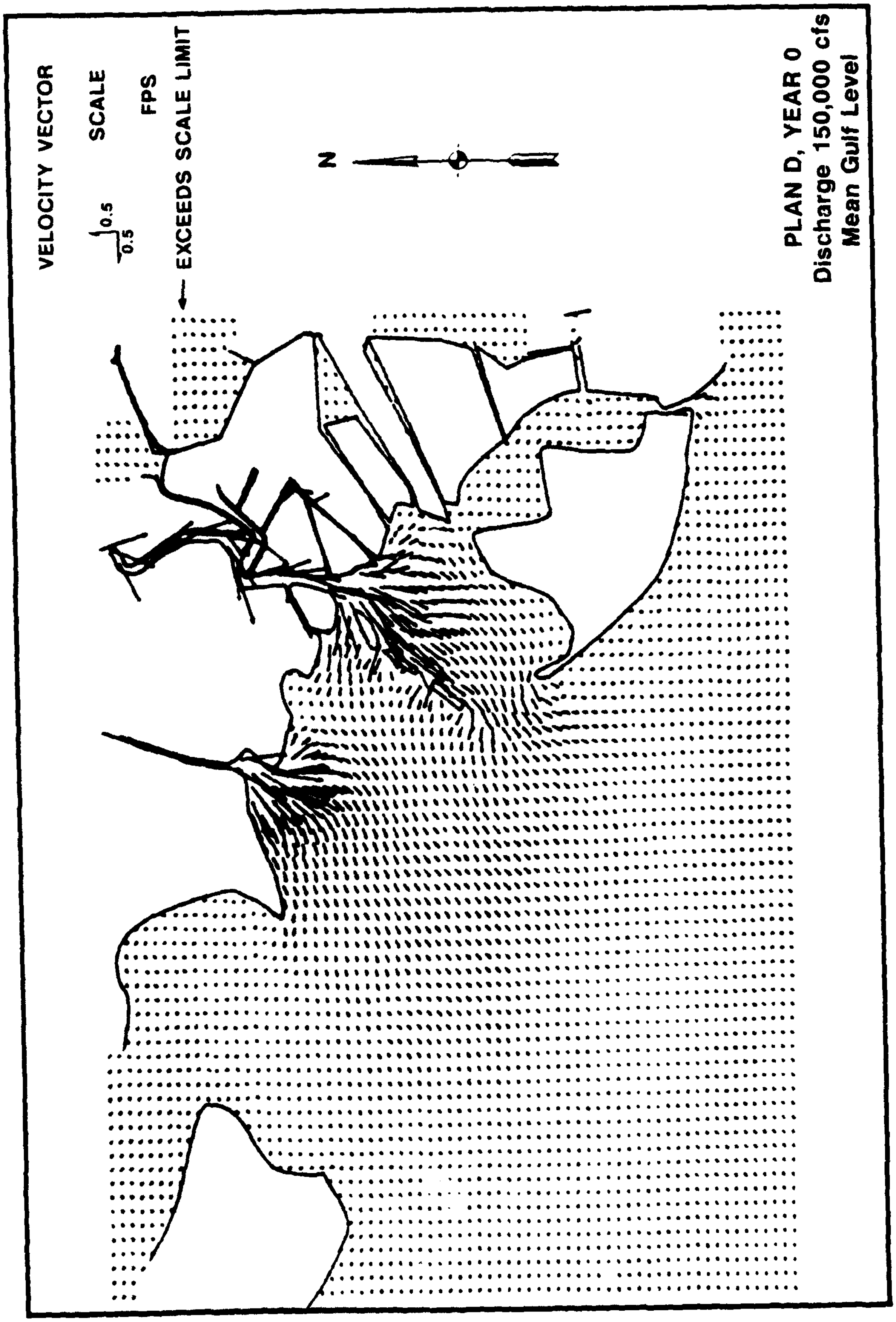
Mean Gulf Level

PLATE 2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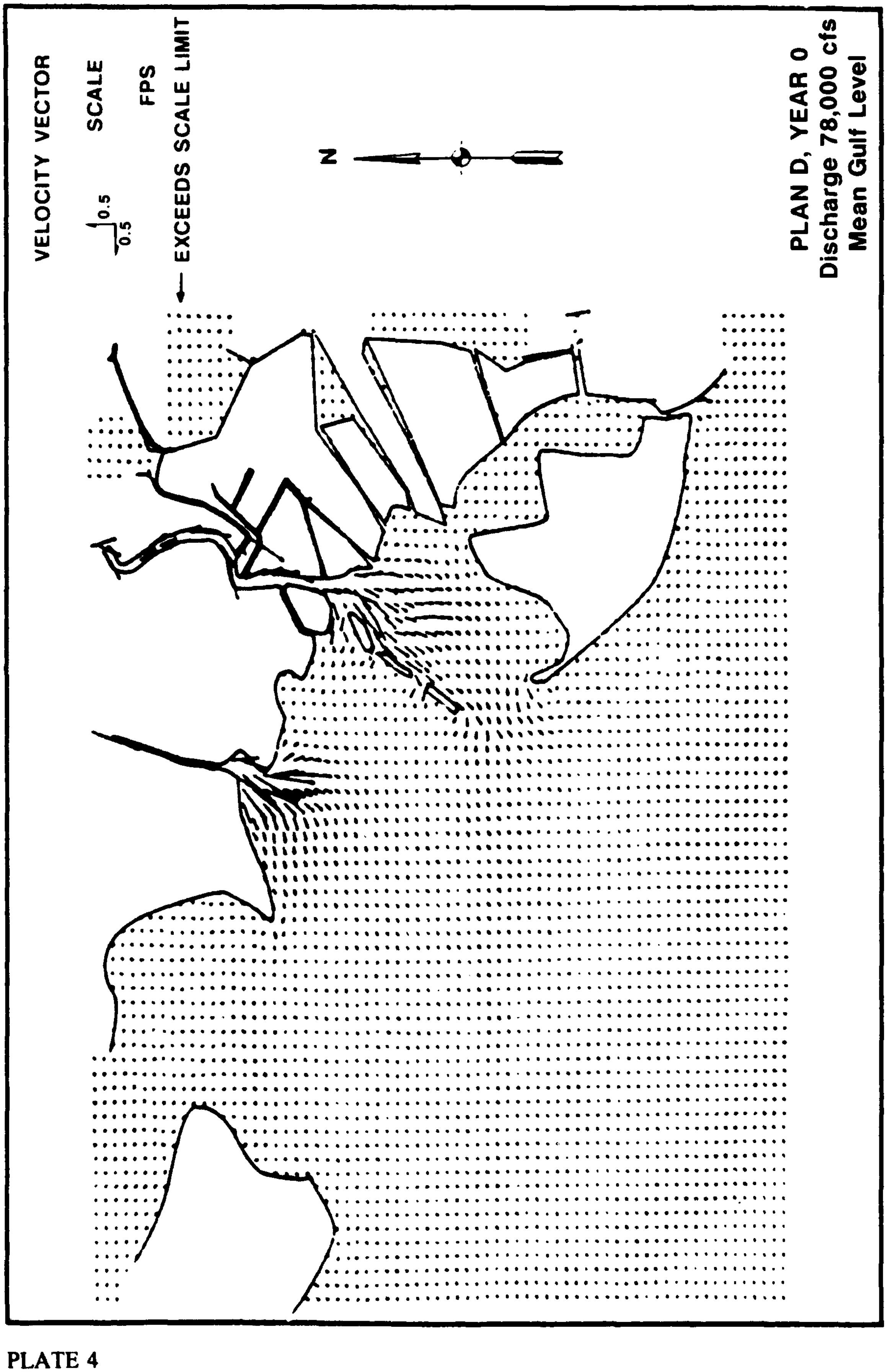
Discharge 150,000 cfs
Mean Gulf Level

PLATE 3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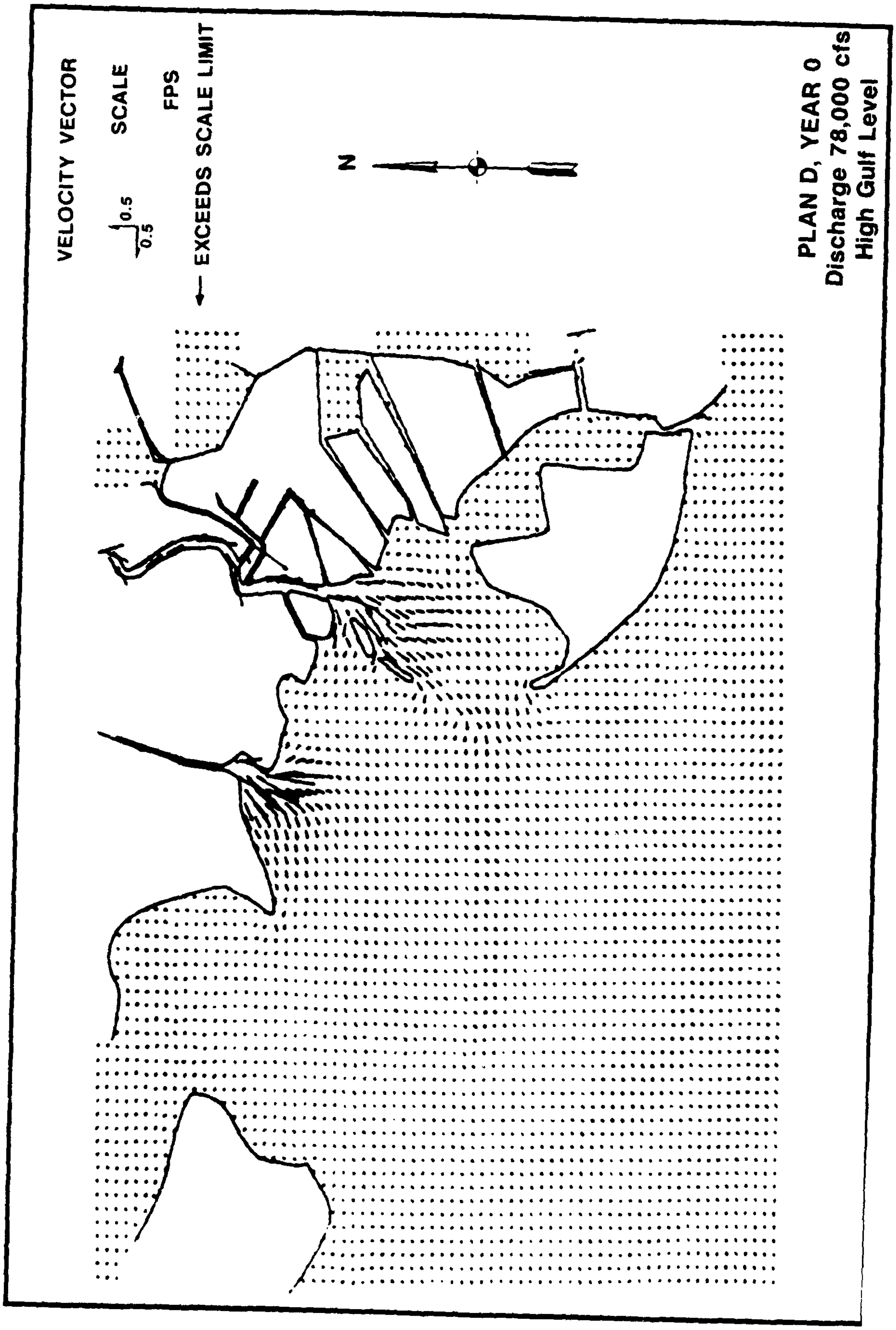
Mean Gulf Level

PLATE 4



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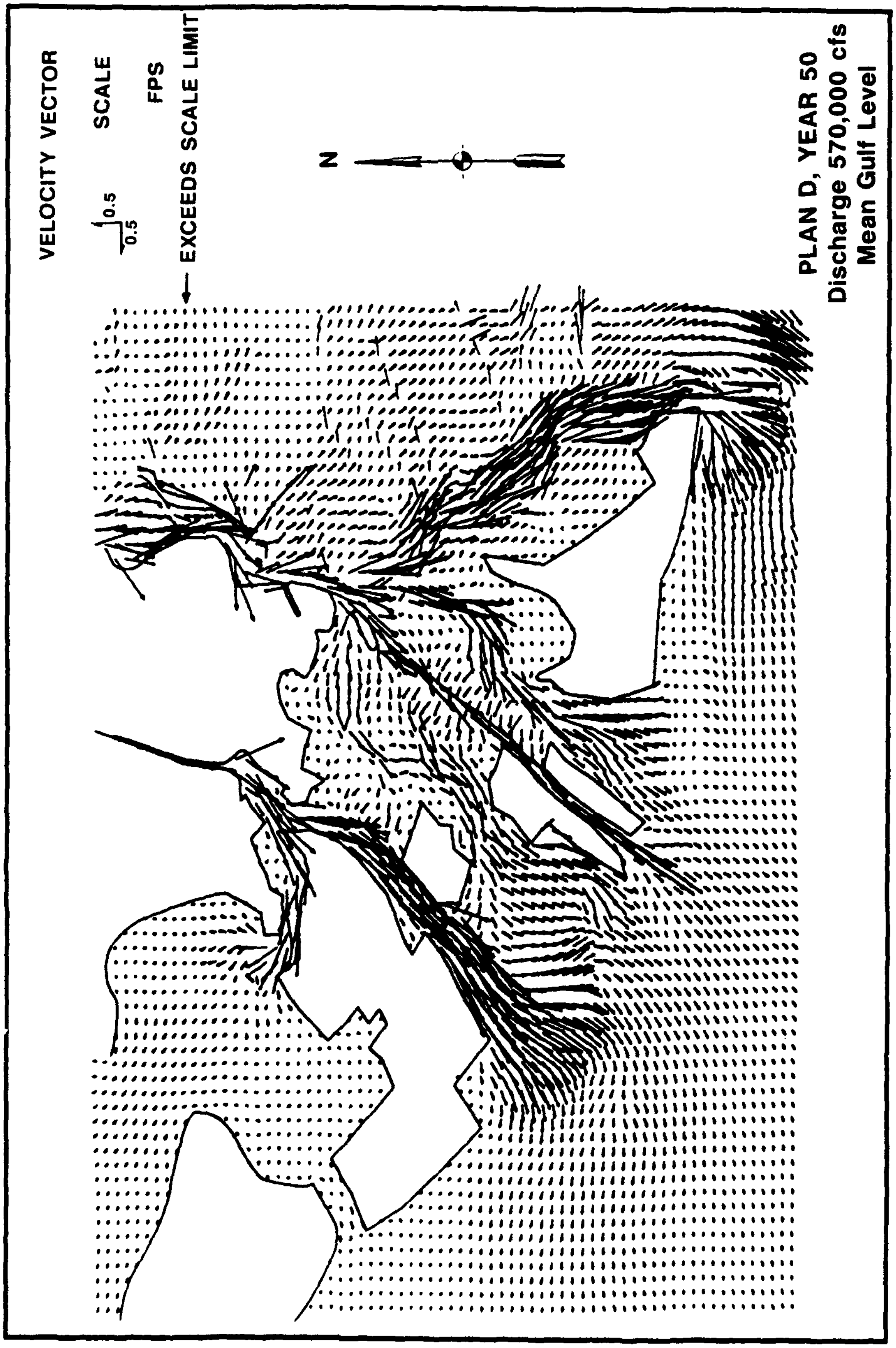
High Gulf Level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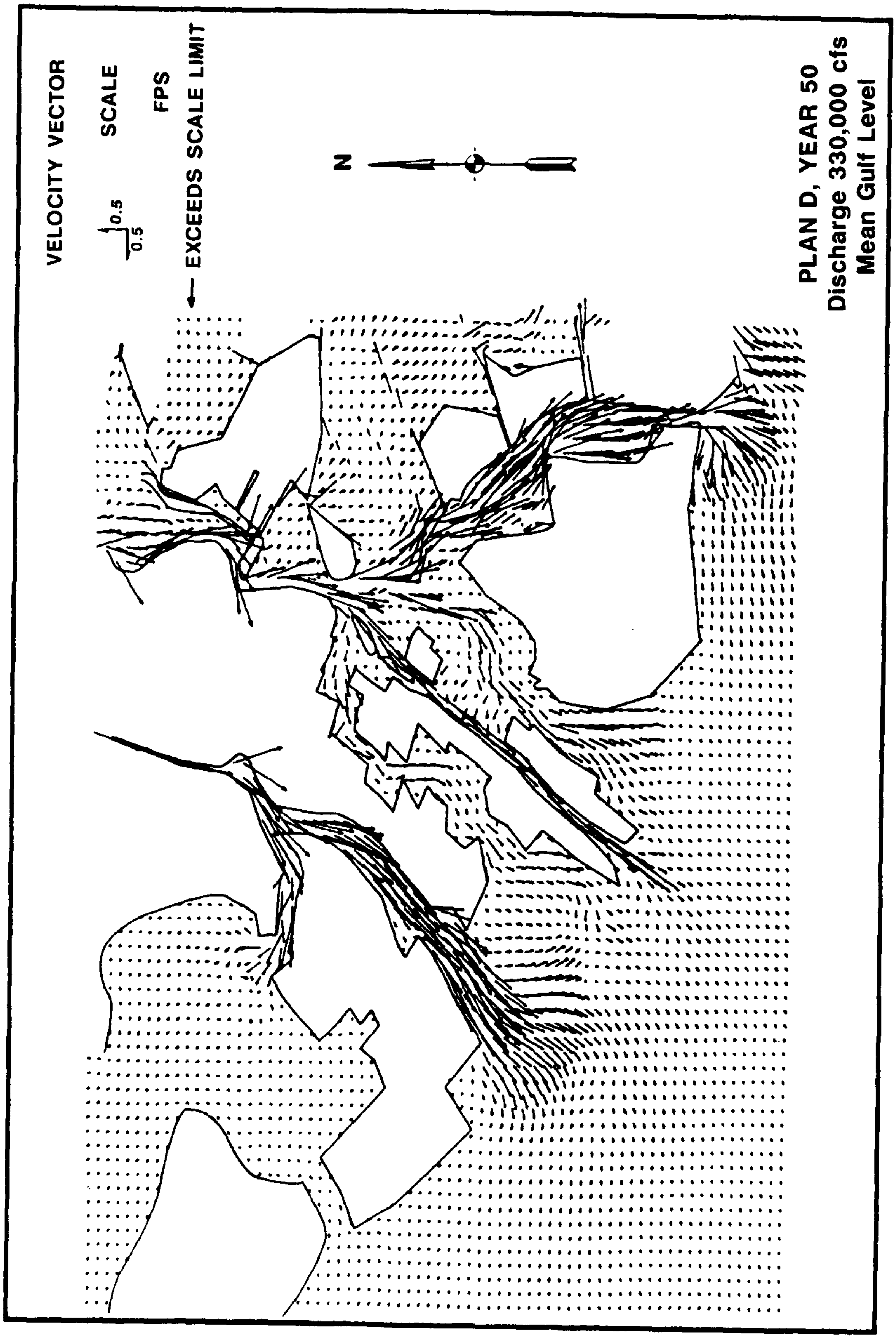
PLAN D, YEAR 50
Discharge 570,000 cfs
Mean Gulf Level

PLATE 6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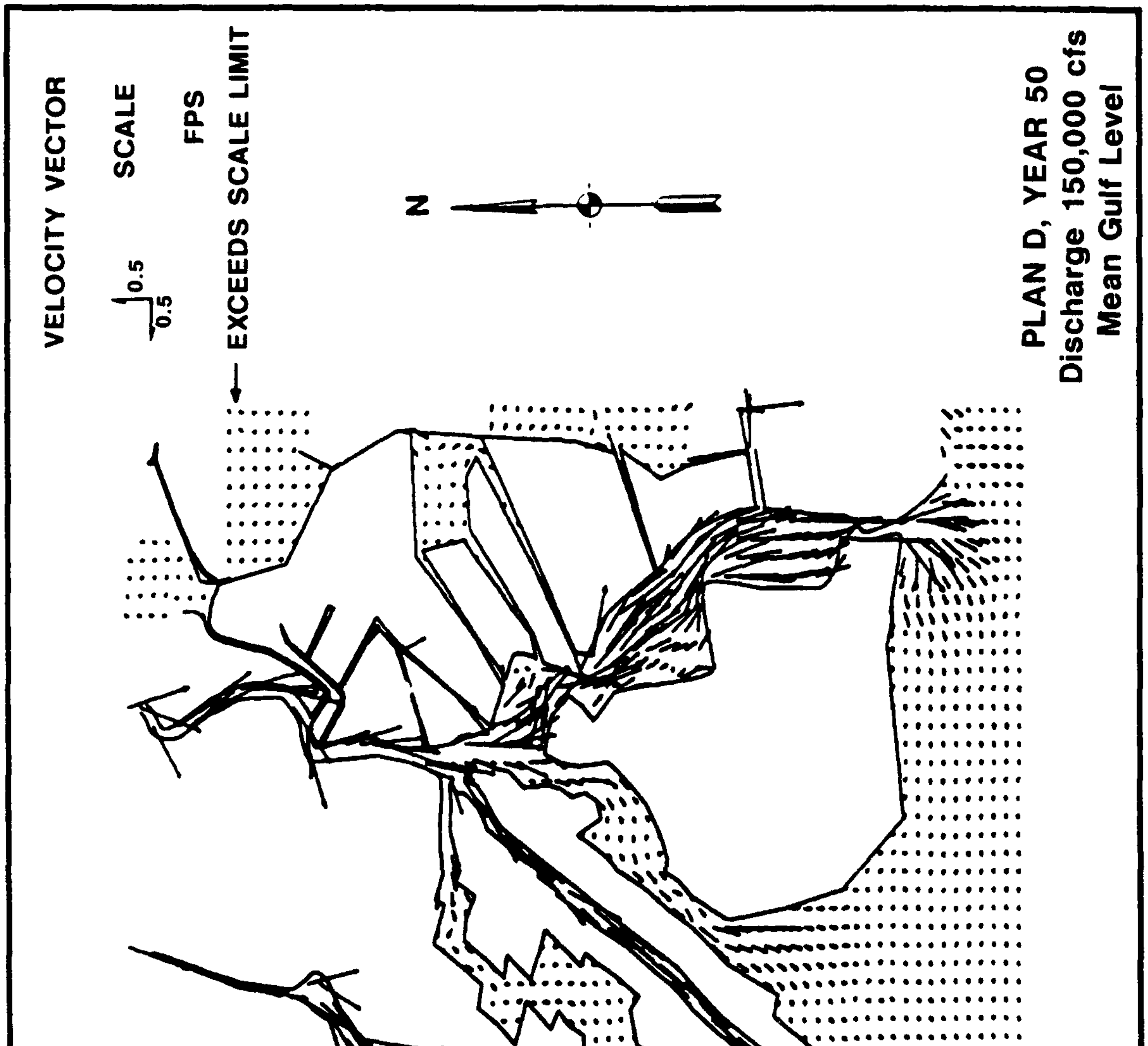
Discharge 330,000 cfs
Mean Gulf Level

PLATE 7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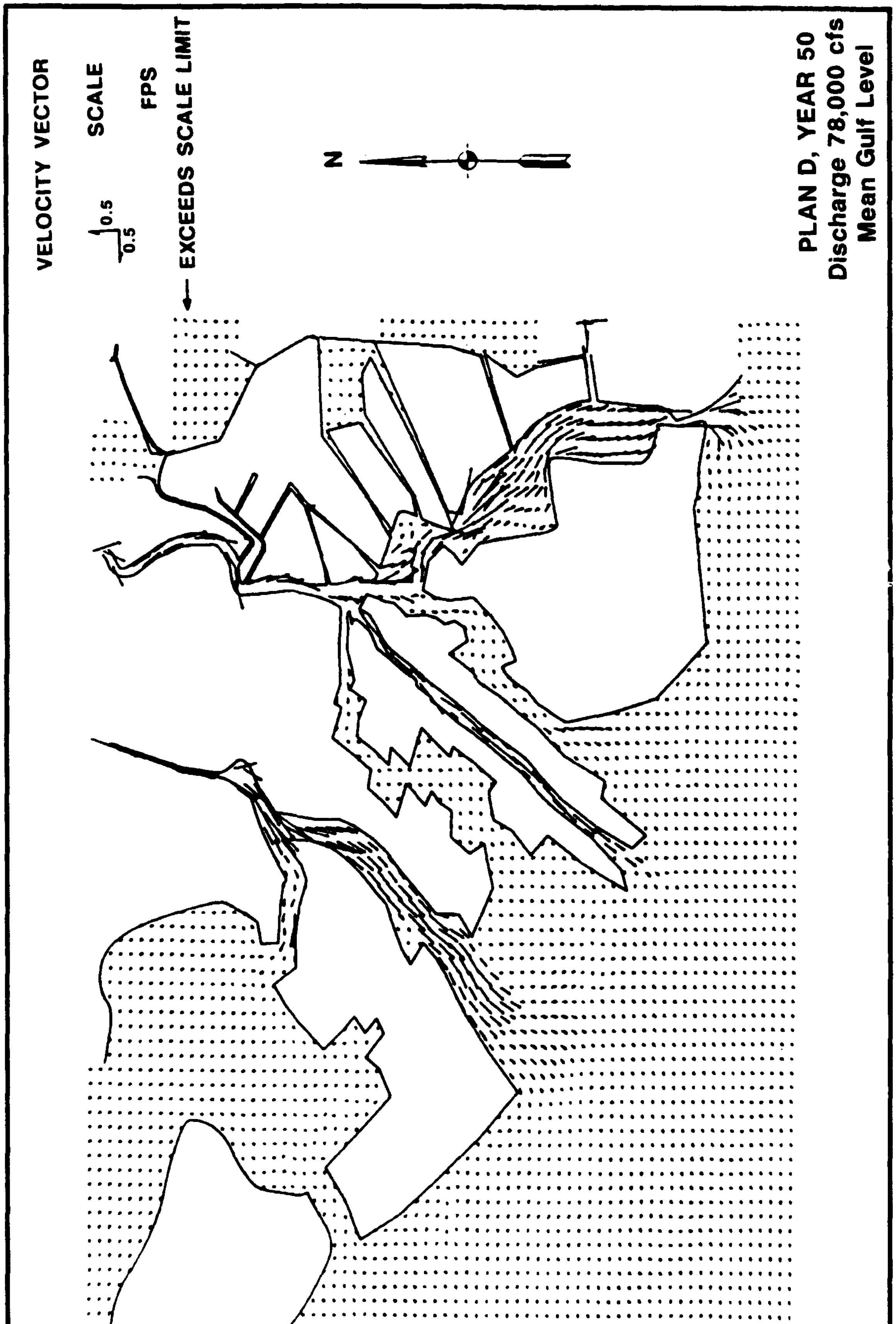
PLAN D, YEAR 50
Discharge 150,000 cfs
Mean Gulf Level

PLATE 8



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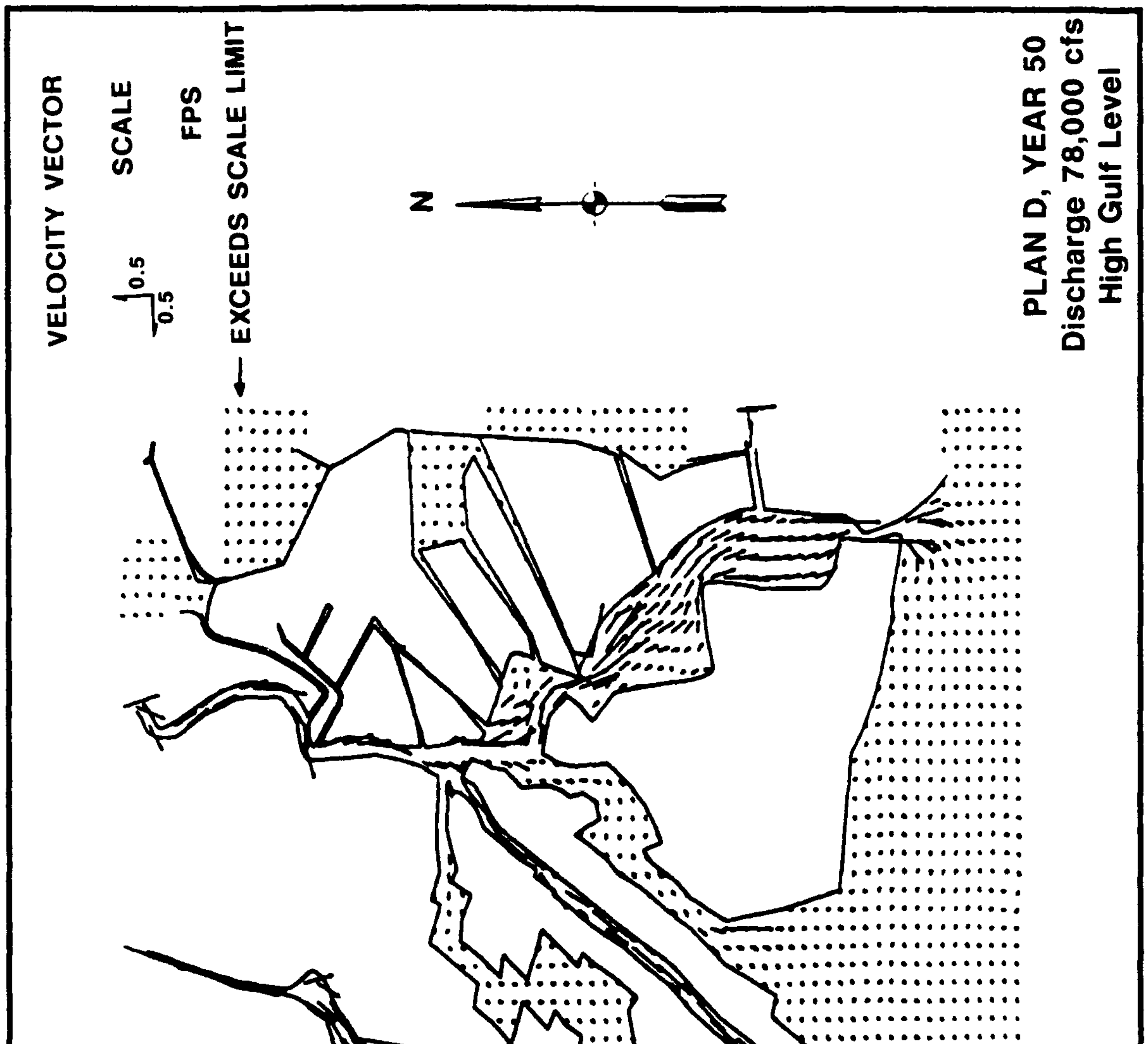
Discharge 78,000 cfs
Mean Gulf Level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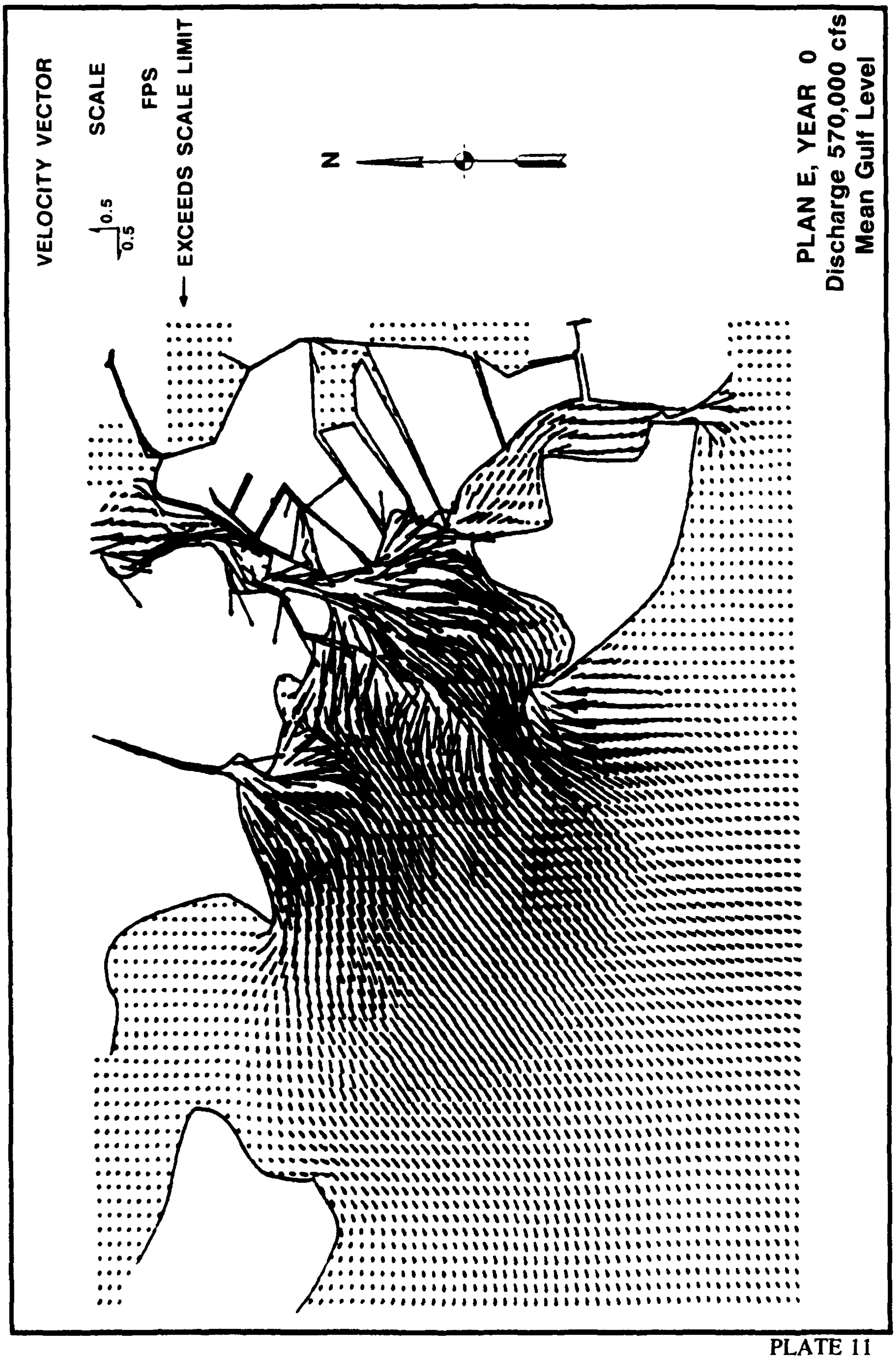
High Gulf Level

PLATE 10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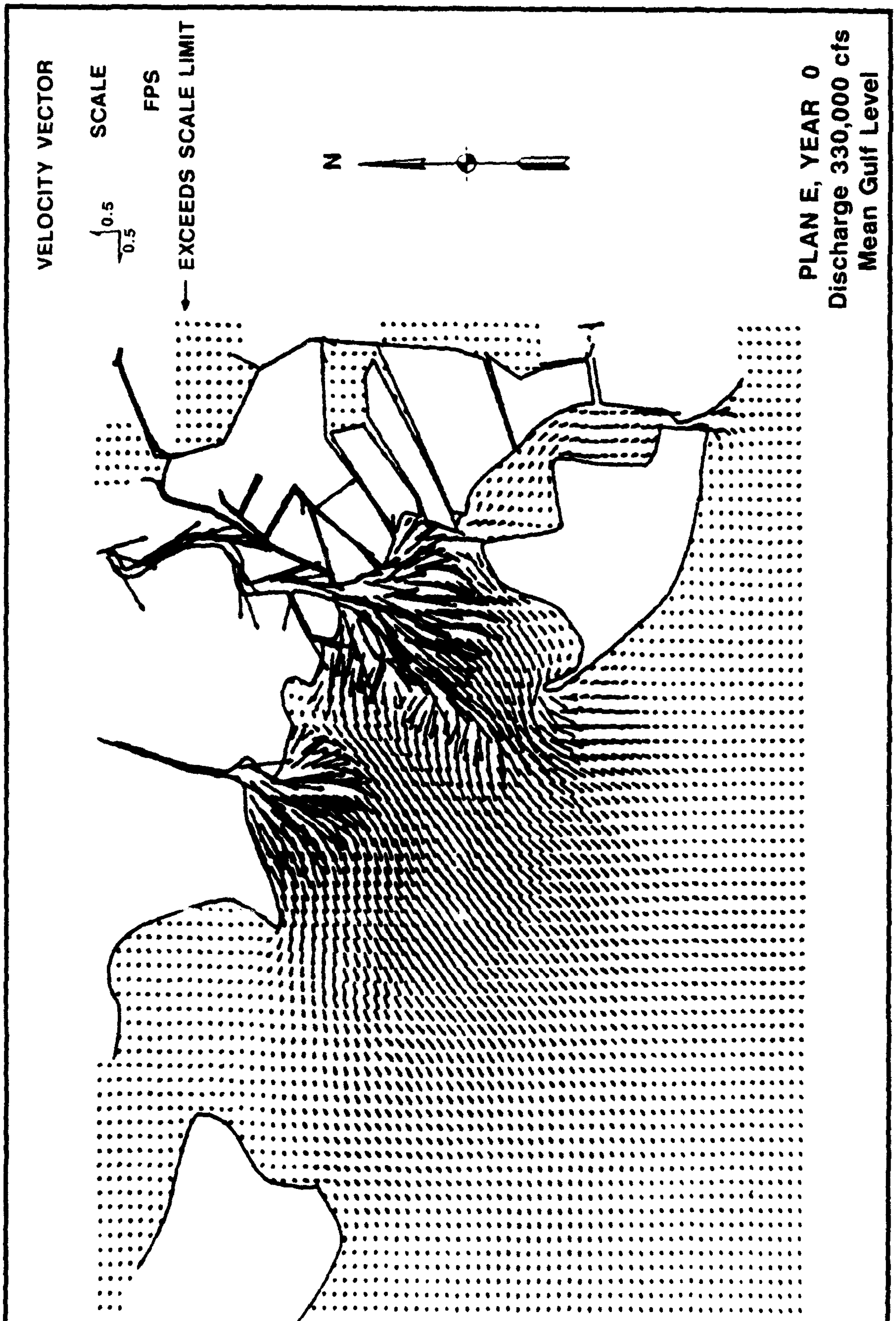
Discharge 570,000 cfs
Mean Gulf Level

PLATE 11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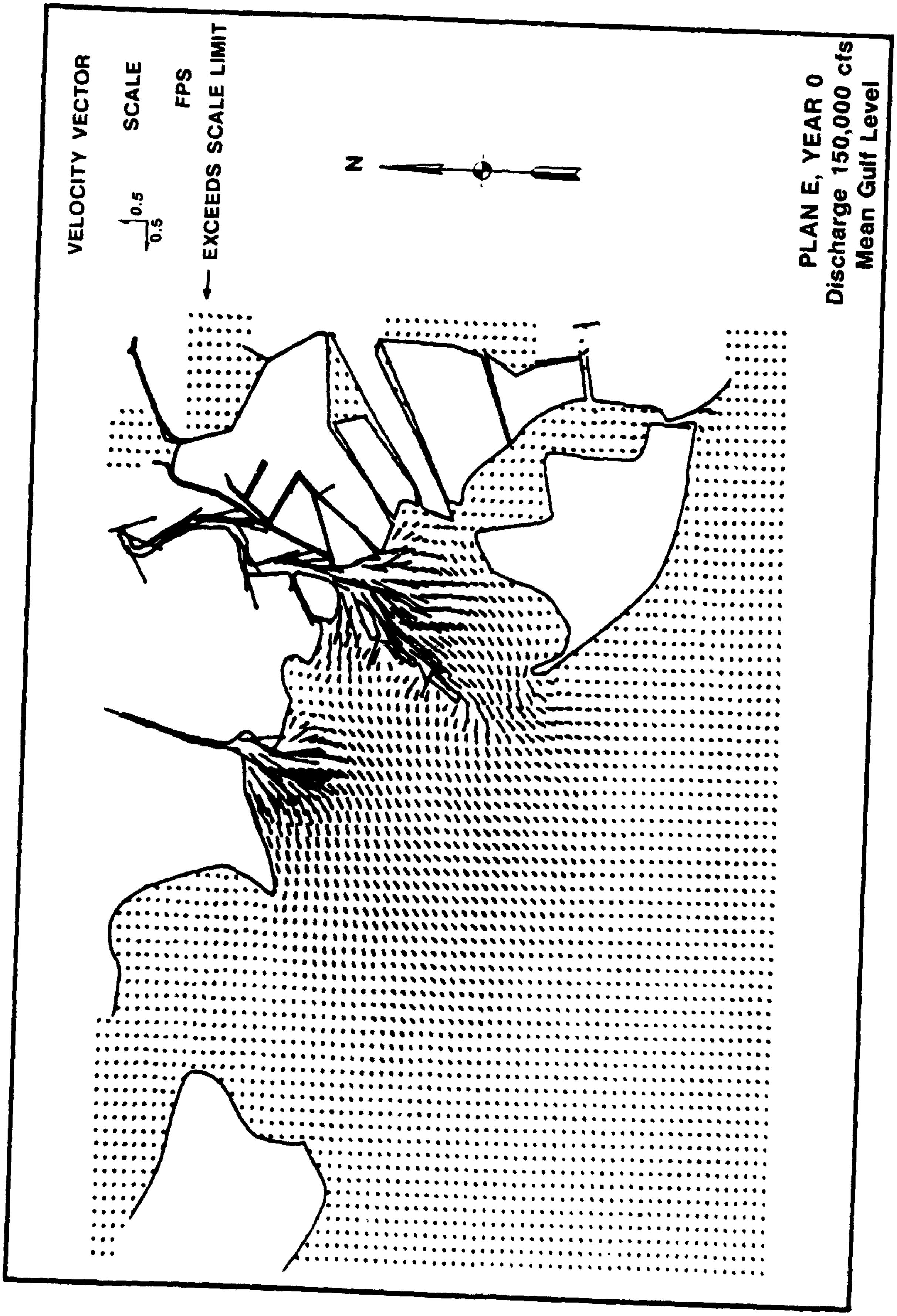
Discharge 330,000 cfs
Mean Gulf Level

PLATE 12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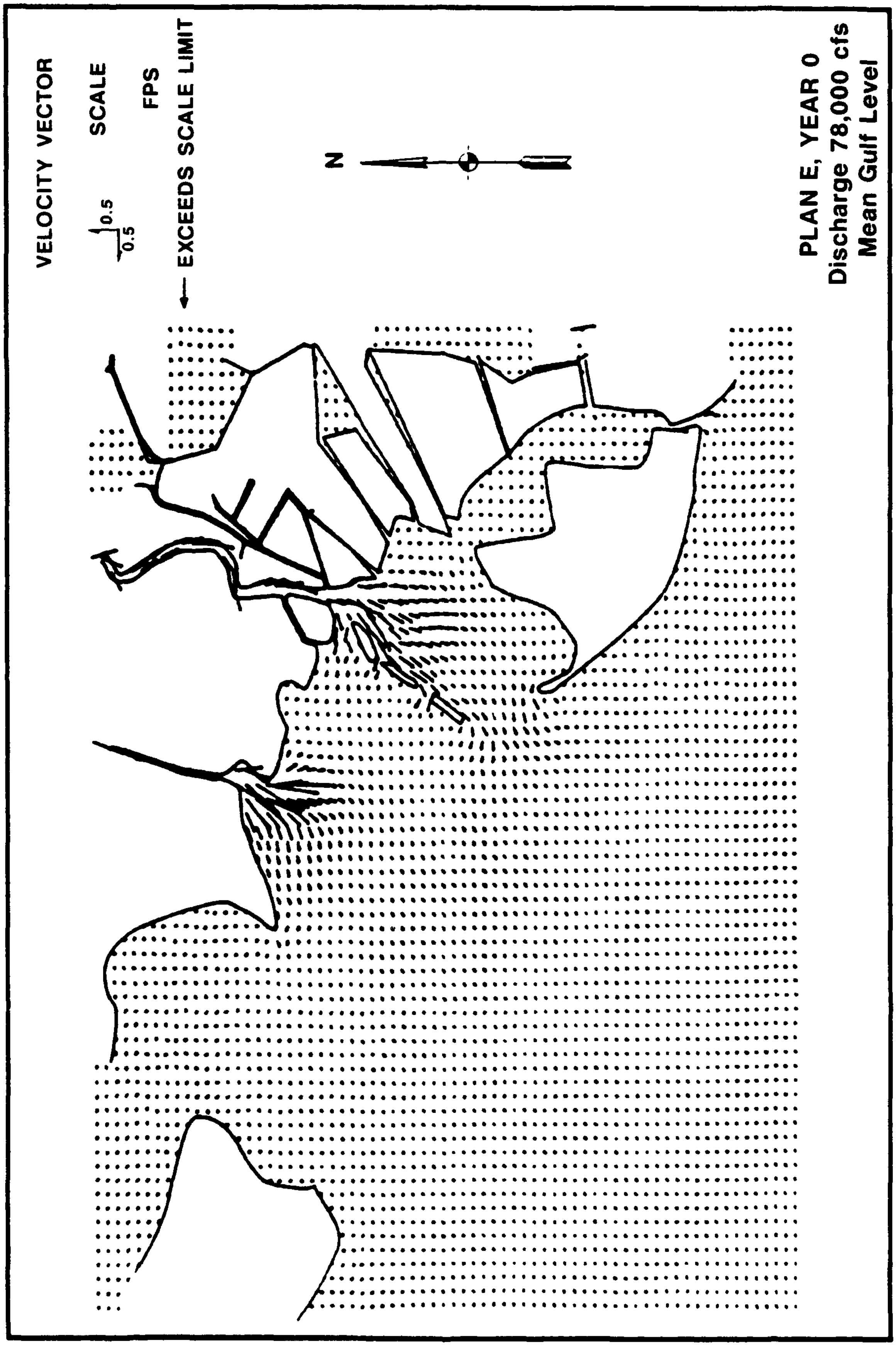
Discharge 150,000 cfs
Mean Gulf Level

PLATE 13



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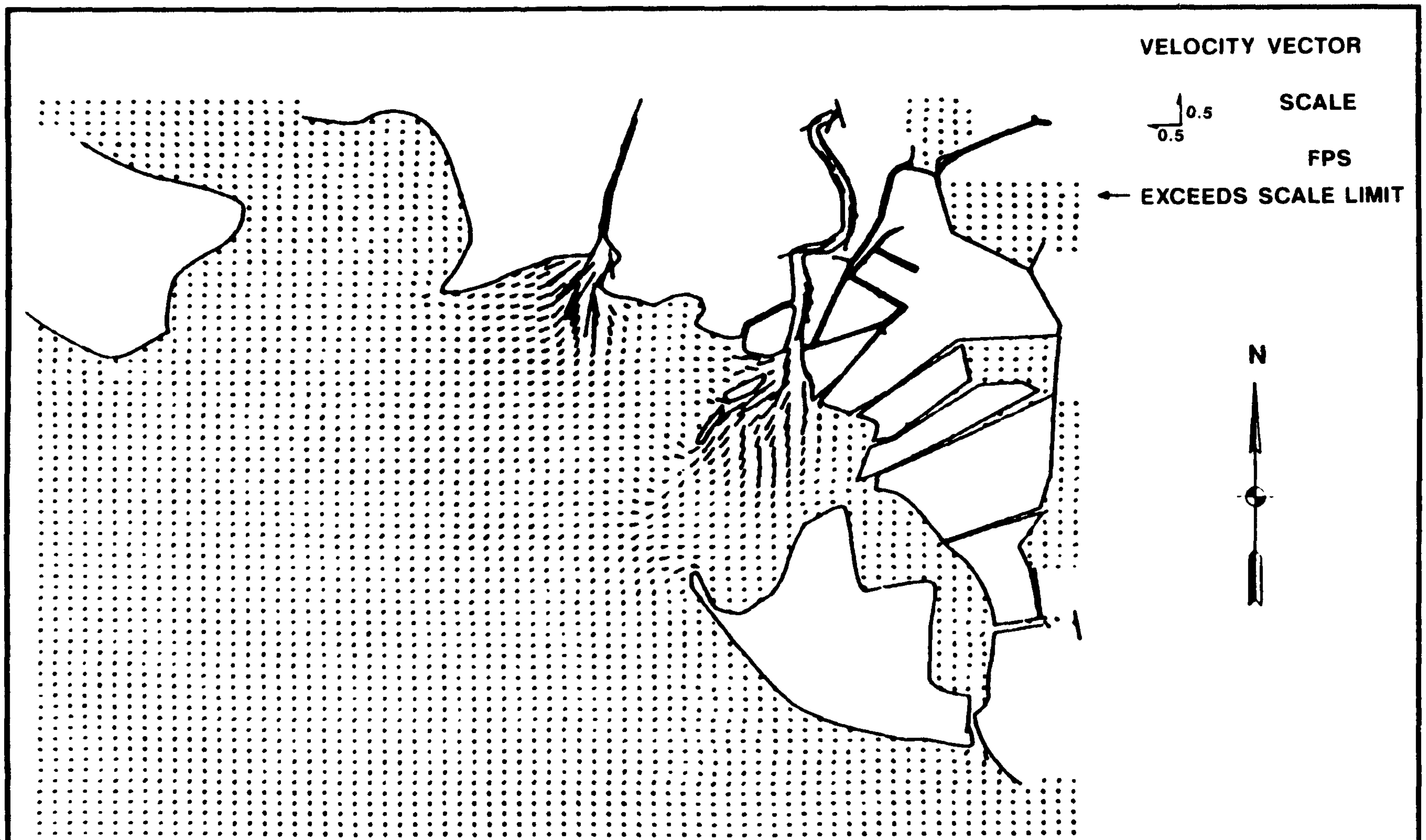
Discharge 78,000 cfs
Mean Gulf Level

PLATE 14



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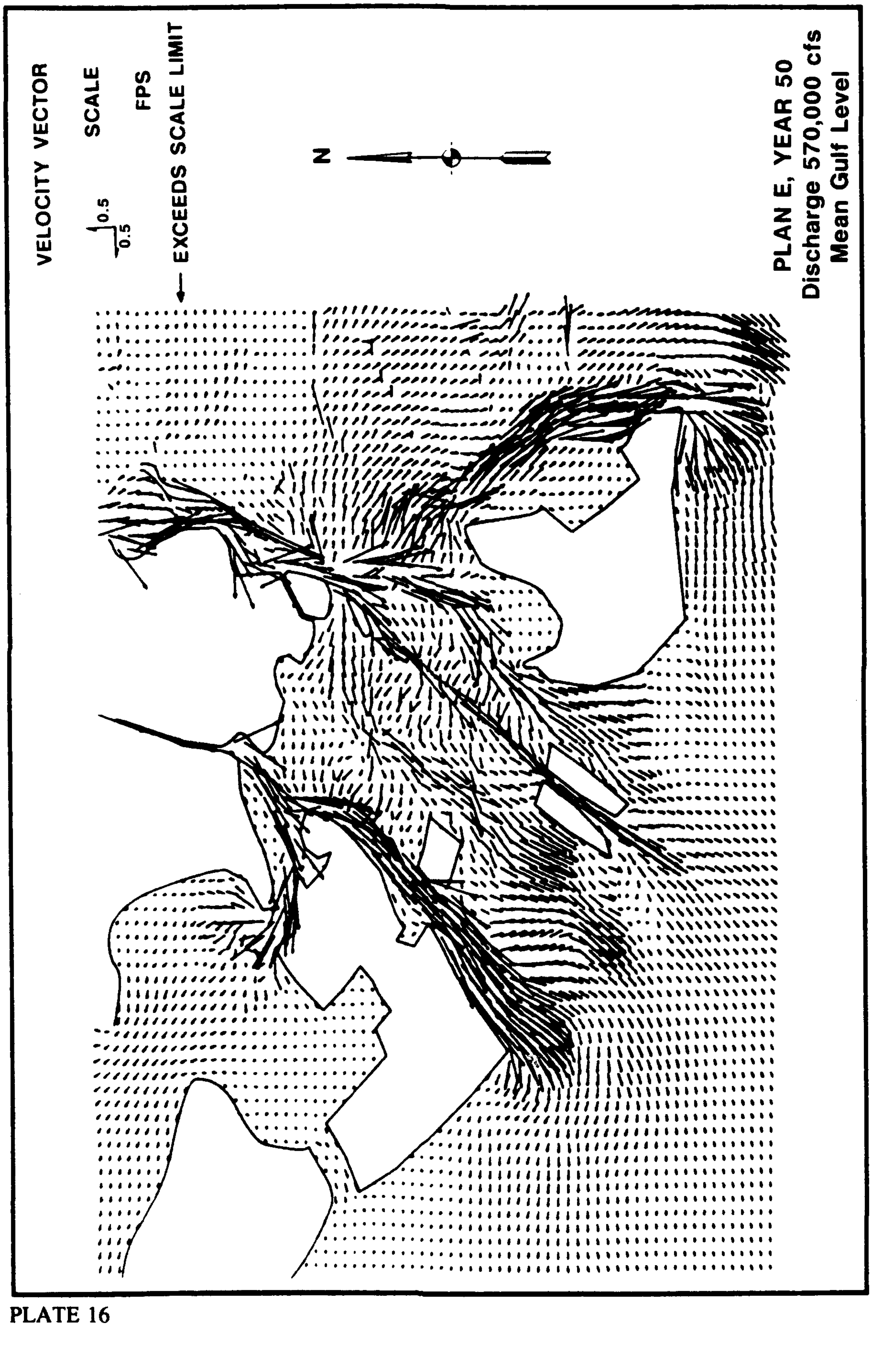
Discharge 78,000 cfs
High Gulf Level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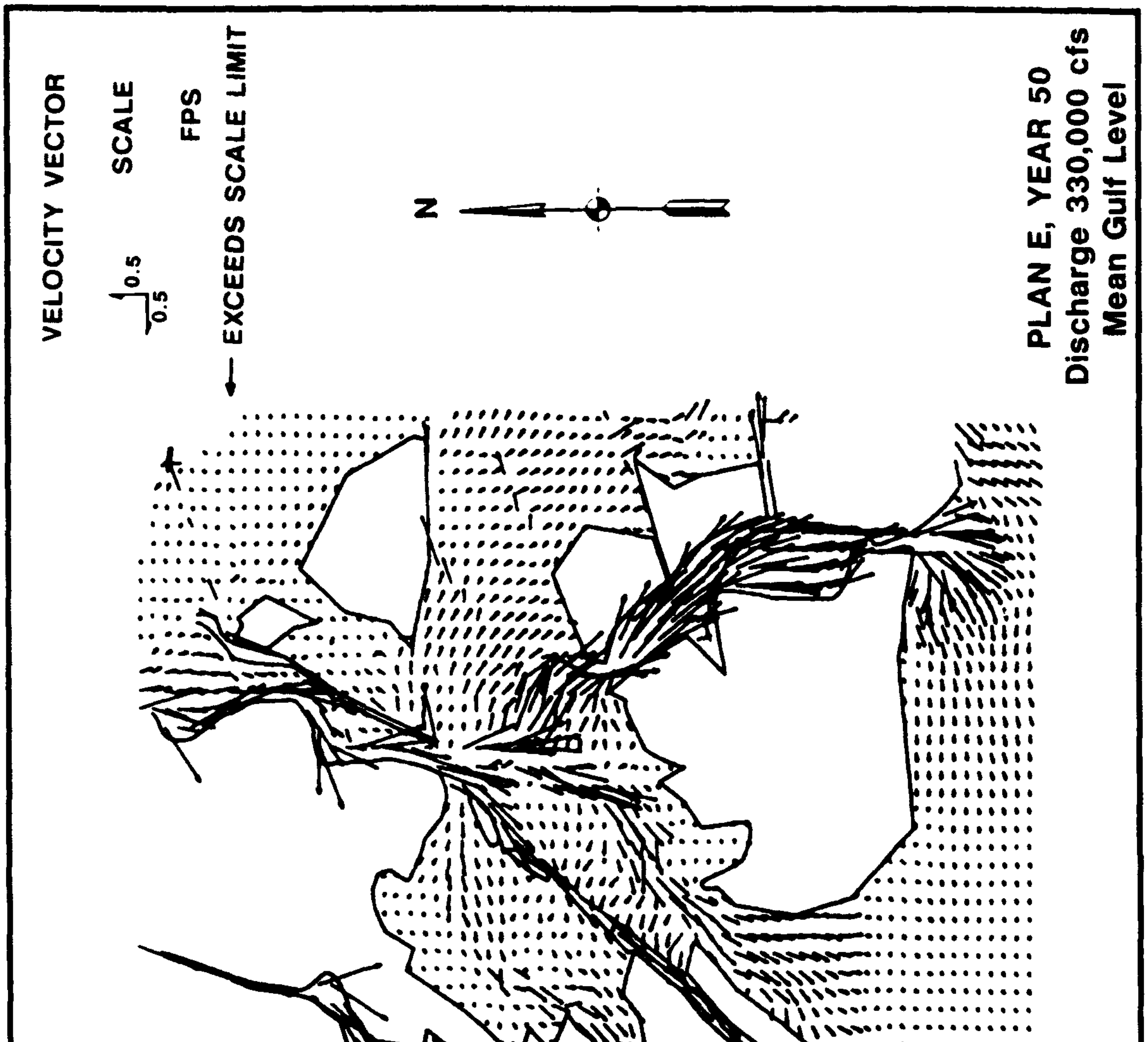
PLAN E, YEAR 50
Discharge 570,000 cfs
Mean Gulf Level

PLATE 16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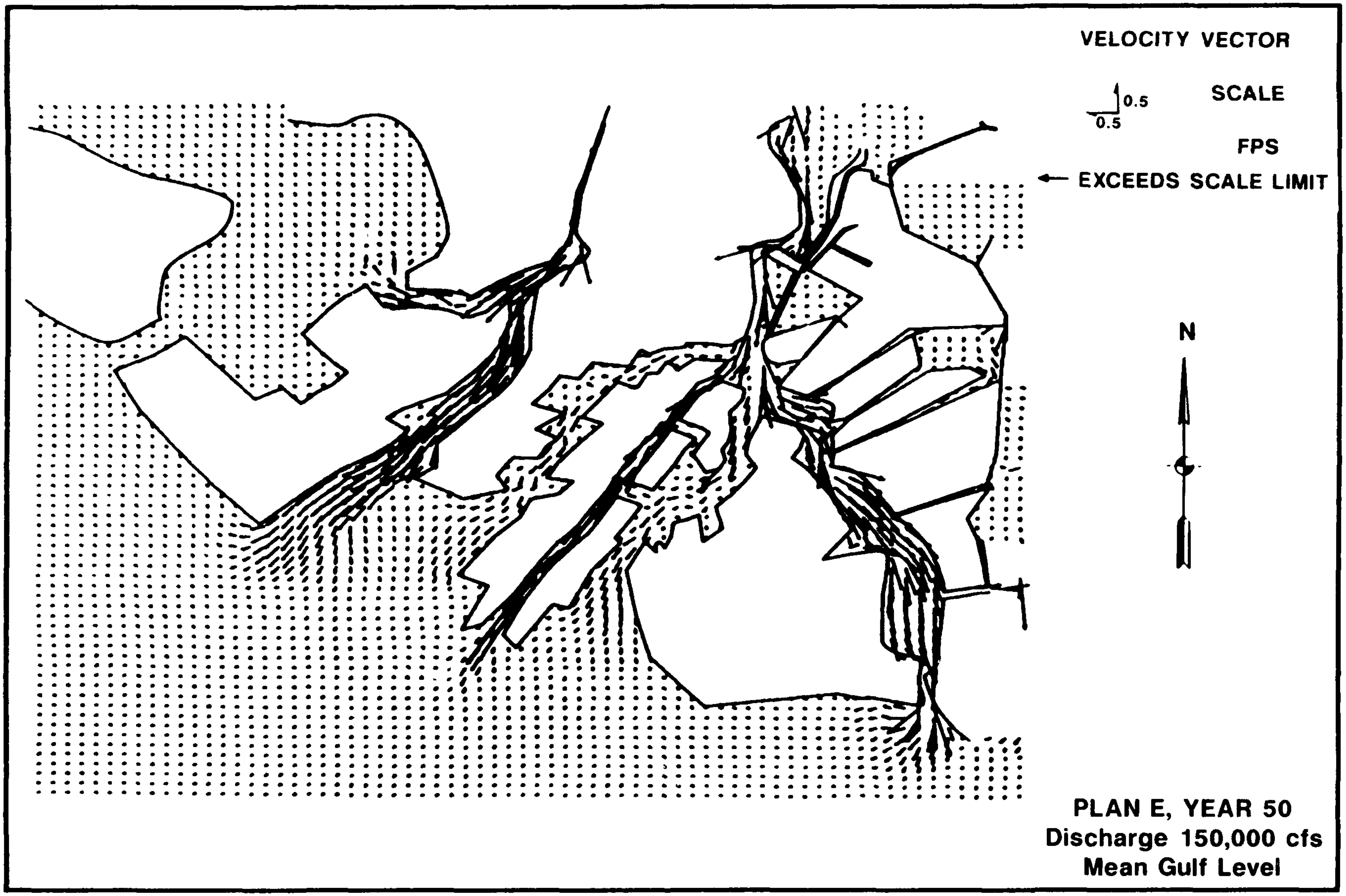
PLAN E, YEAR 50
Discharge 330,000 cfs
Mean Gulf Level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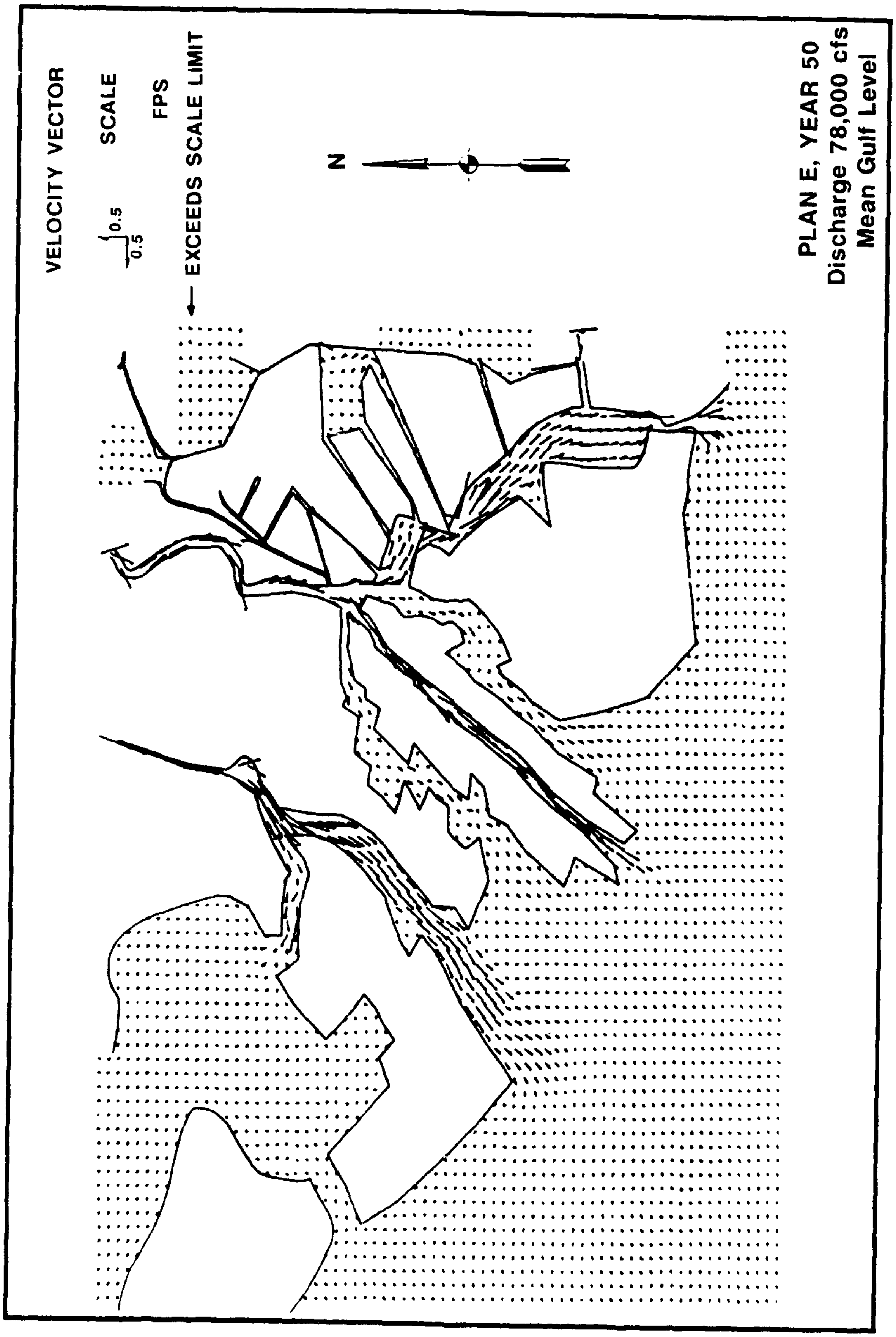
PLAN E, YEAR 50
Discharge 150,000 cfs
Mean Gulf Level

PLATE 18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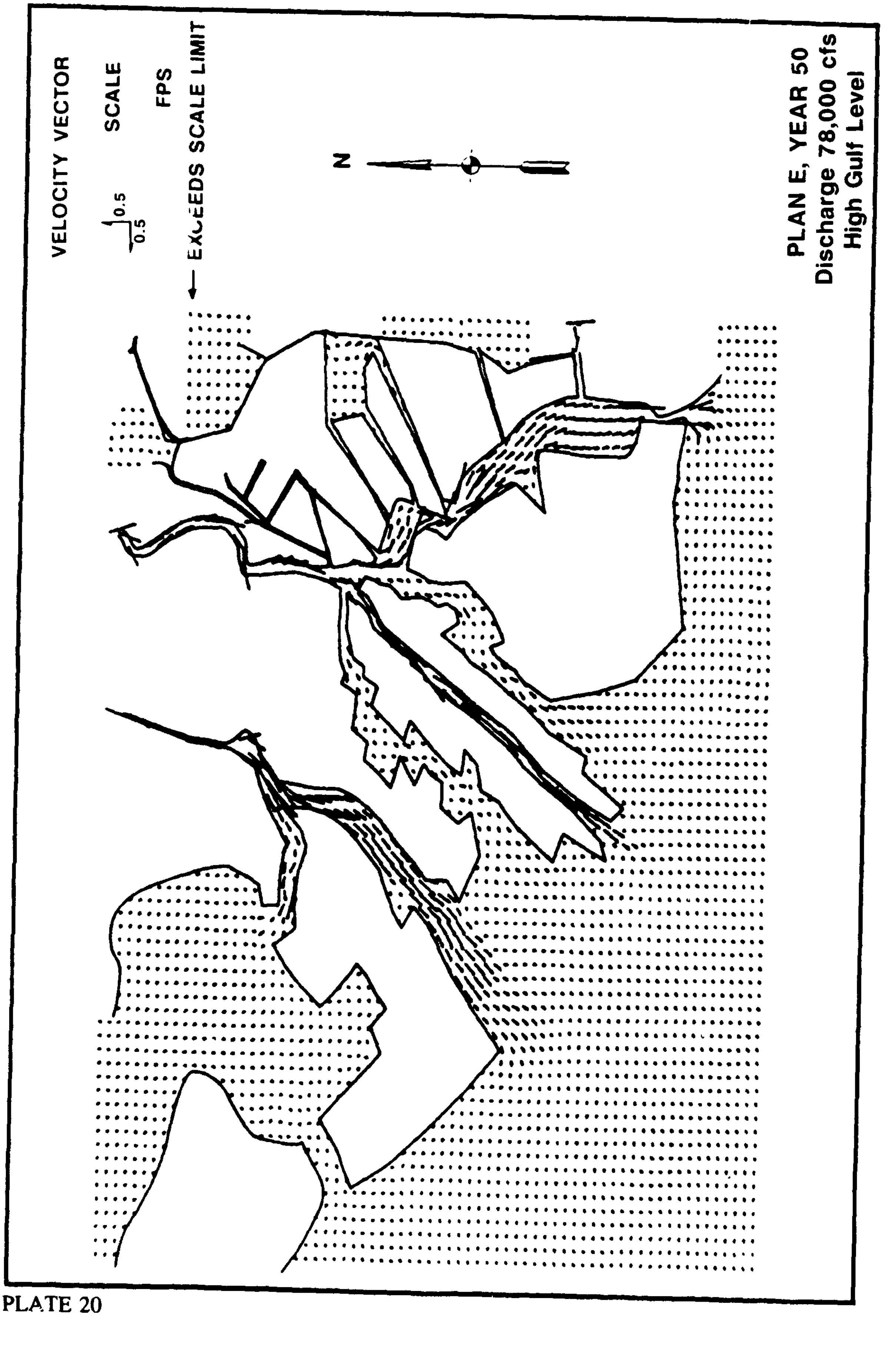
Discharge 78,000 cfs
Mean Gulf Level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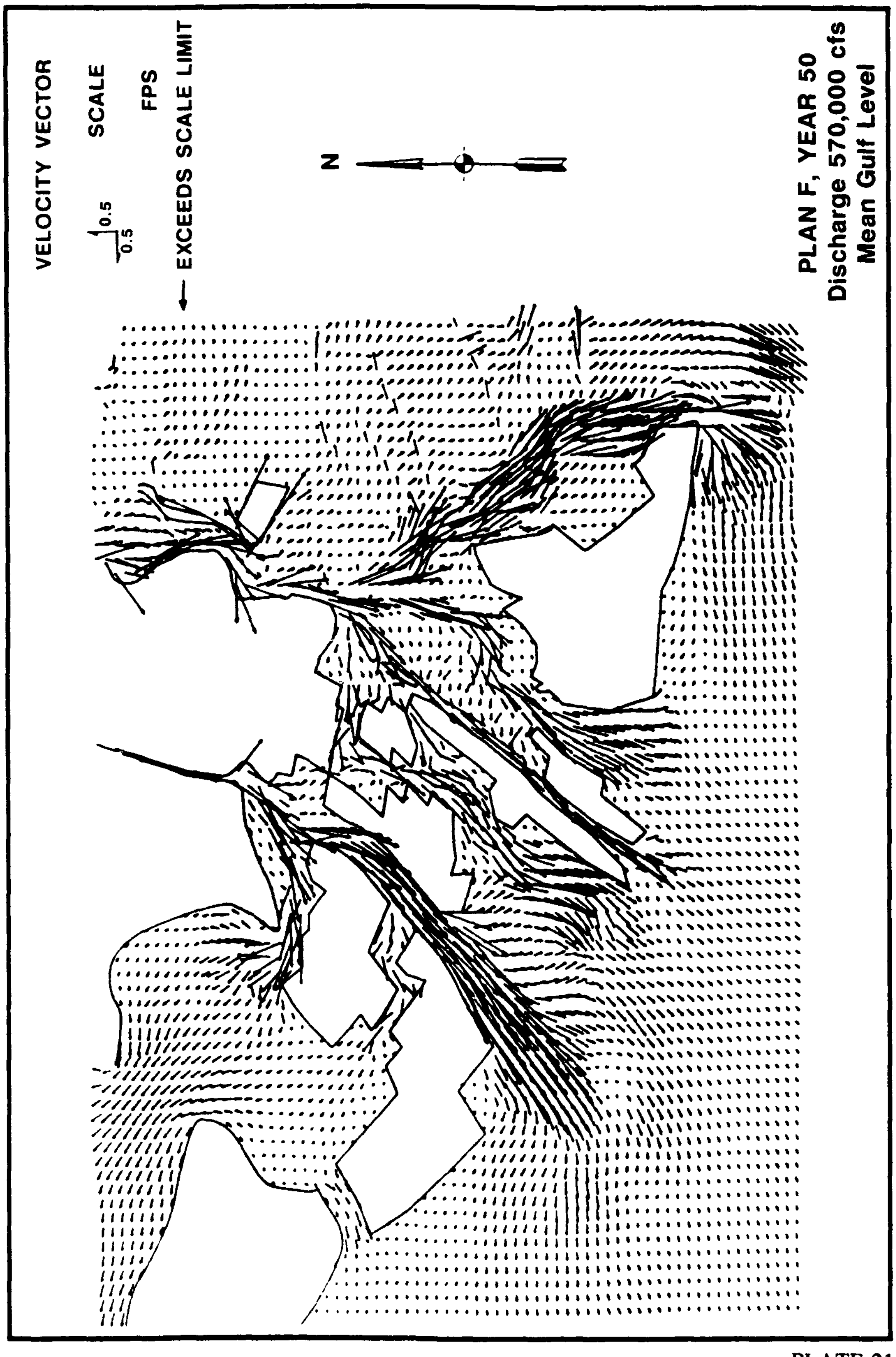
PLAN E, YEAR 50
Discharge 78,000 cfs
High Gulf Level

PLATE 20



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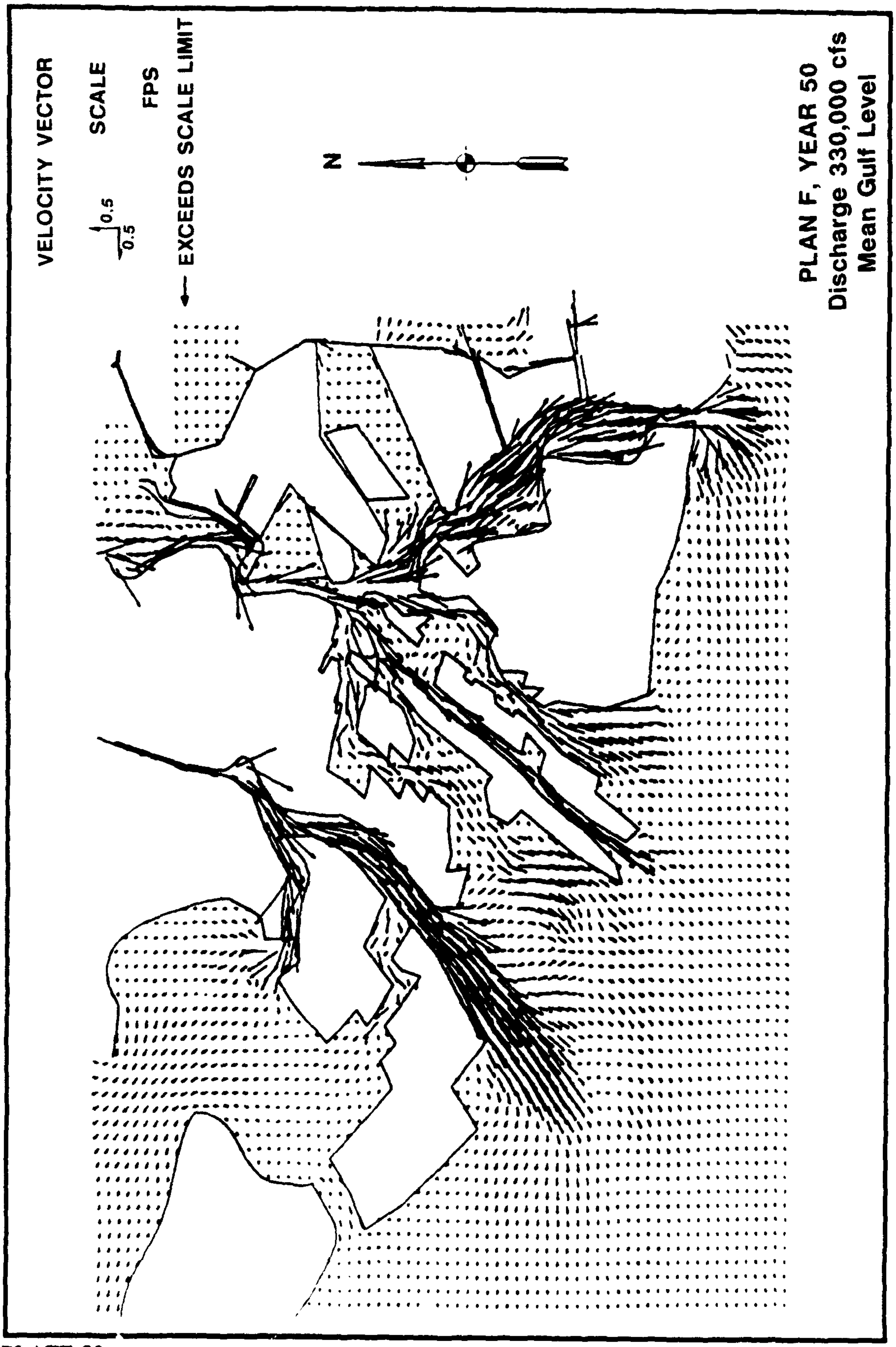
PLAN F, YEAR 50
Discharge 570,000 cfs
Mean Gulf Level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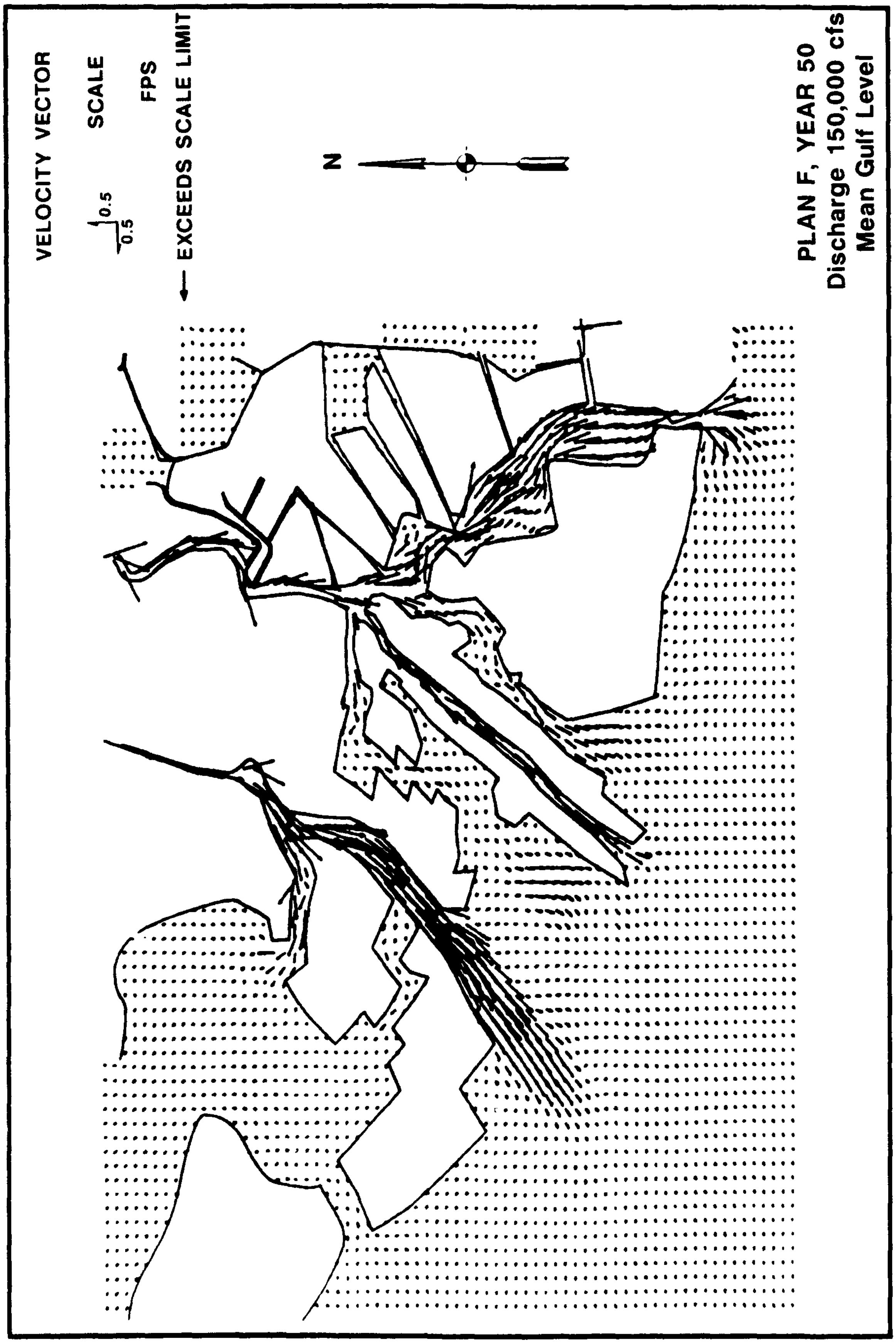
Discharge 330,000 cfs
Mean Gulf Level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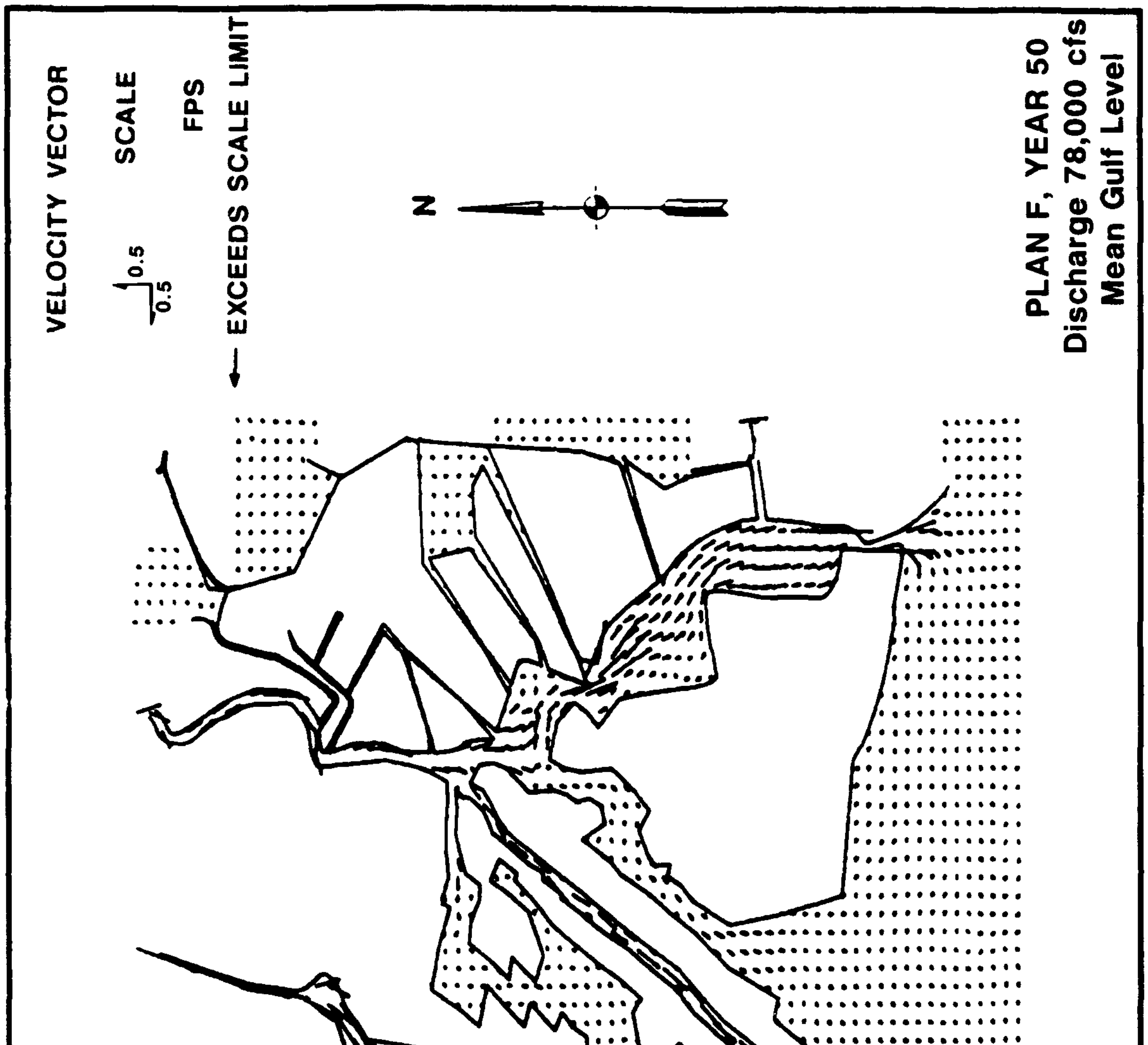
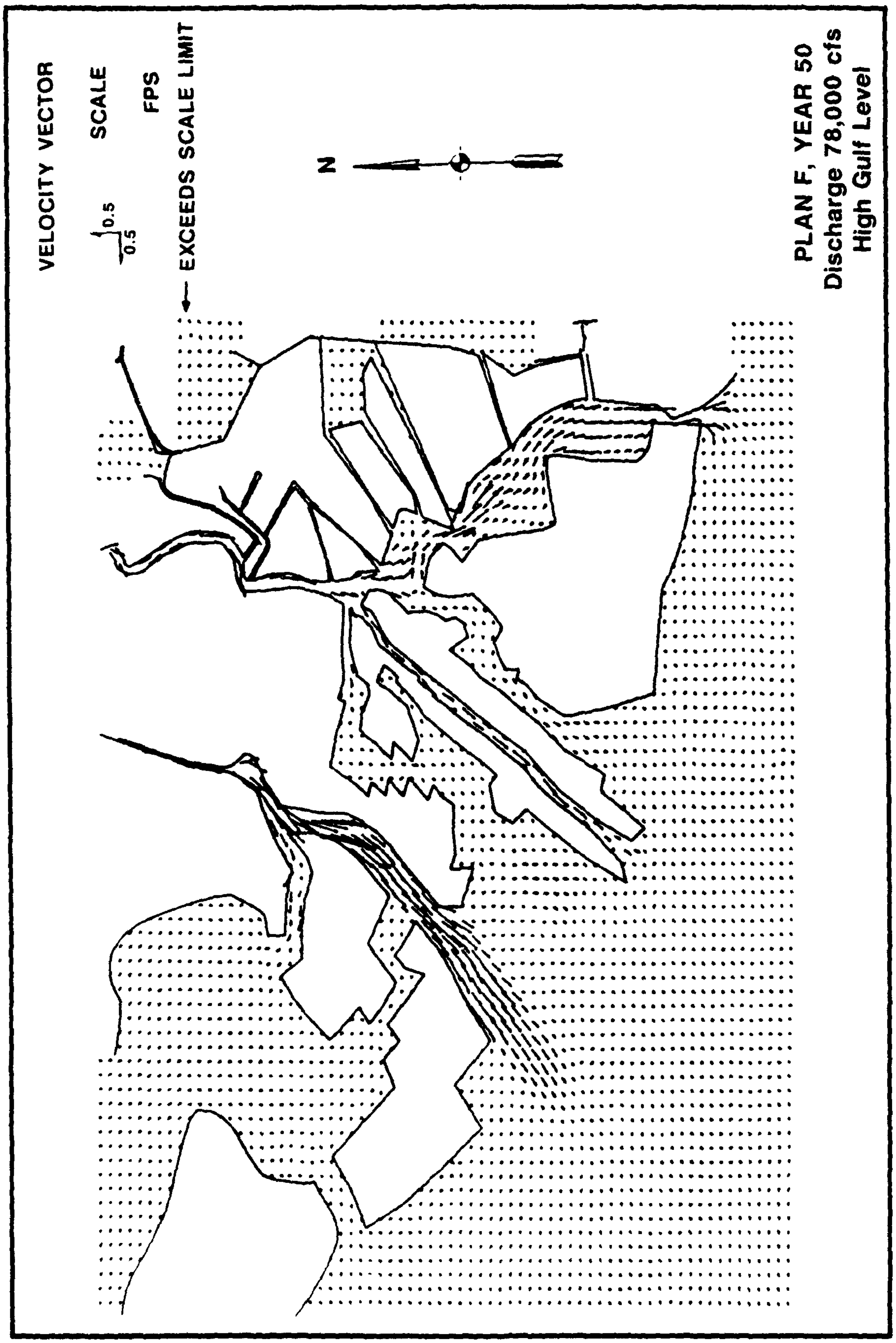
PLAN F, YEAR 50
Discharge 150,000 cfs
Mean Gulf Level

PLATE 23



PLAN F, YEAR 50
Discharge 78,000 cfs
Mean Gulf Level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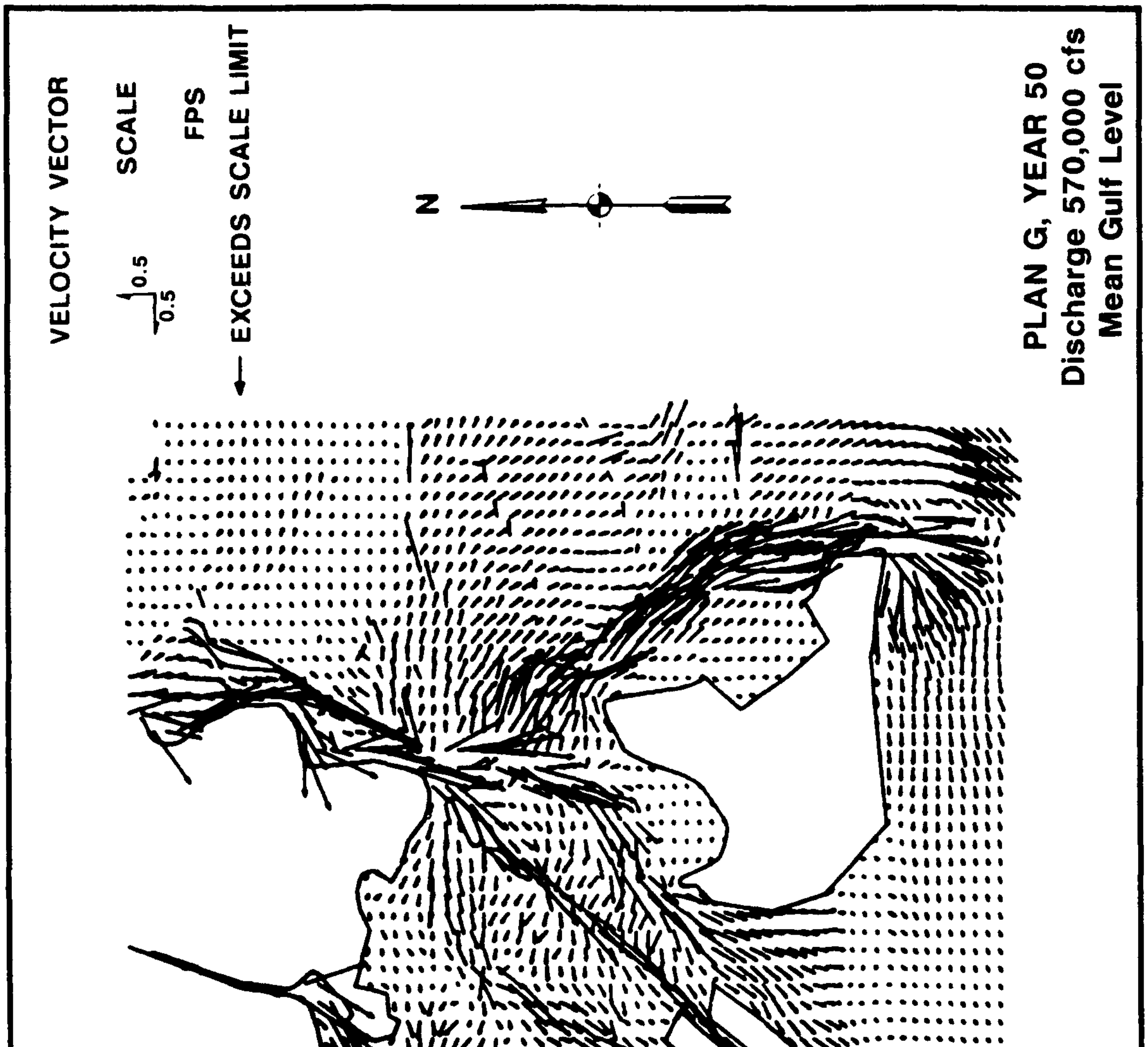
PLAN F, YEAR 50
Discharge 78,000 cfs
High Gulf Level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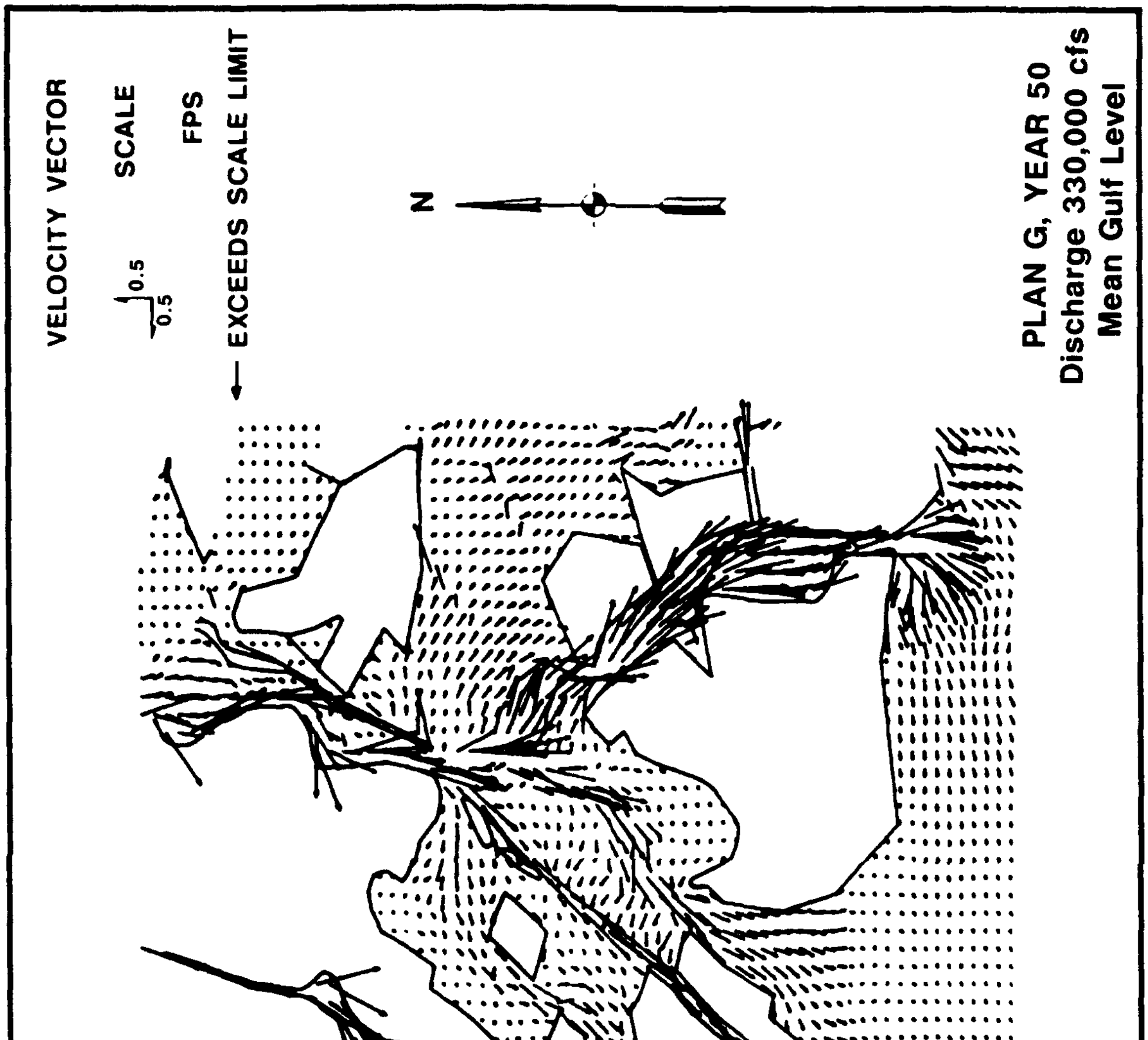
PLAN G, YEAR 50
Discharge 570,000 cfs
Mean Gulf Level

PLATE 26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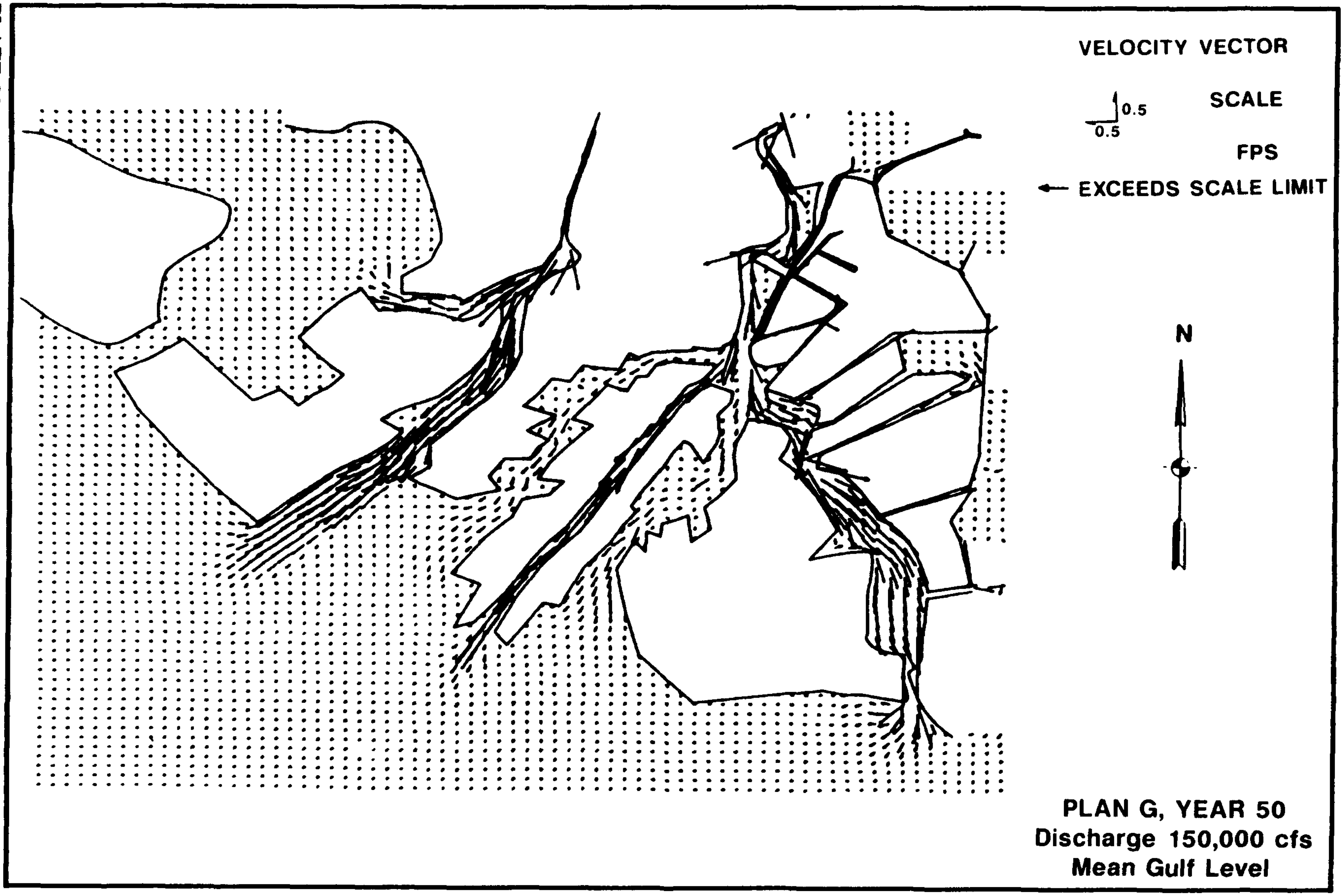
PLAN G, YEAR 50
Discharge 330,000 cfs
Mean Gulf Level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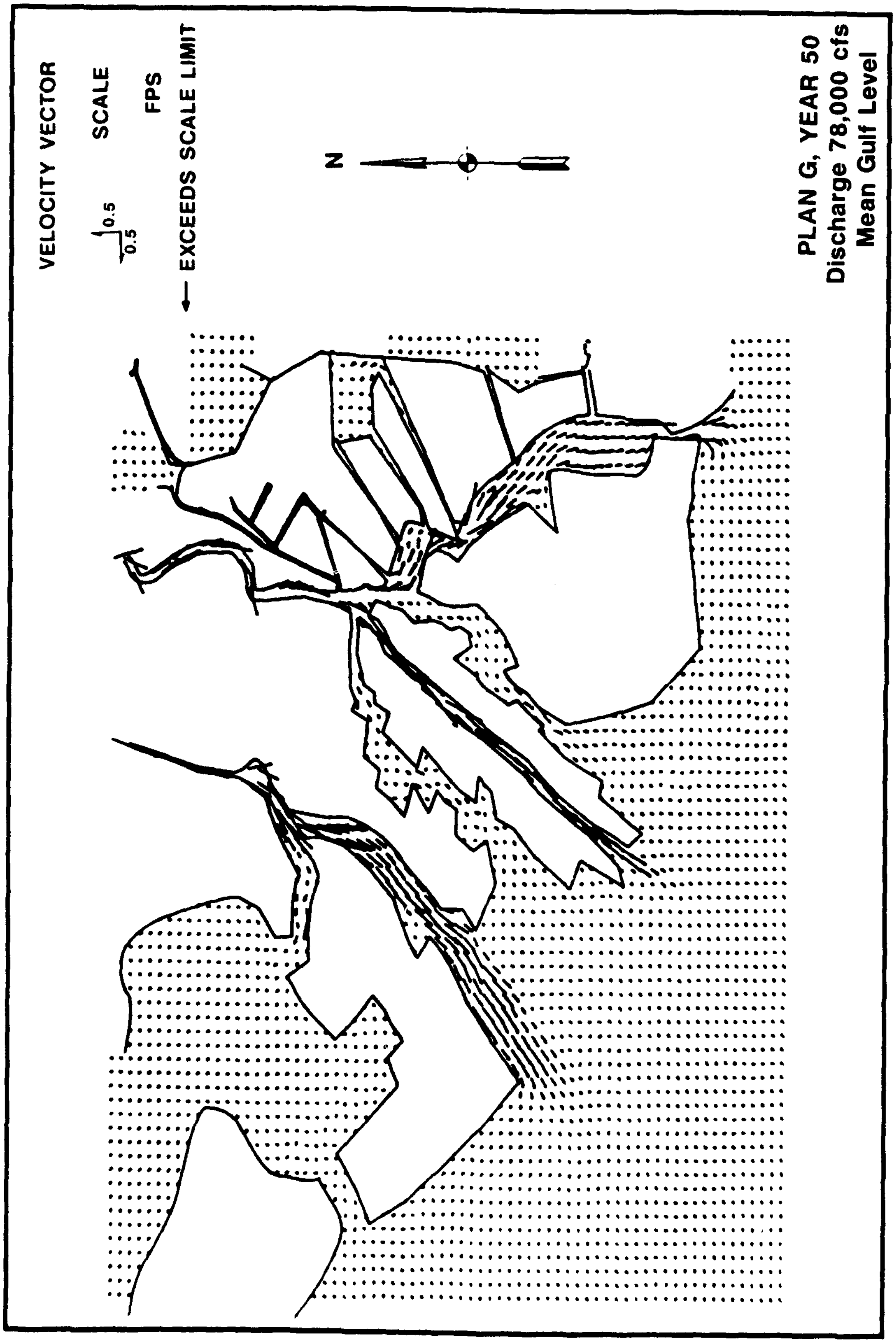
PLAN G, YEAR 50
Discharge 150,000 cfs
Mean Gulf Level

PLATE 28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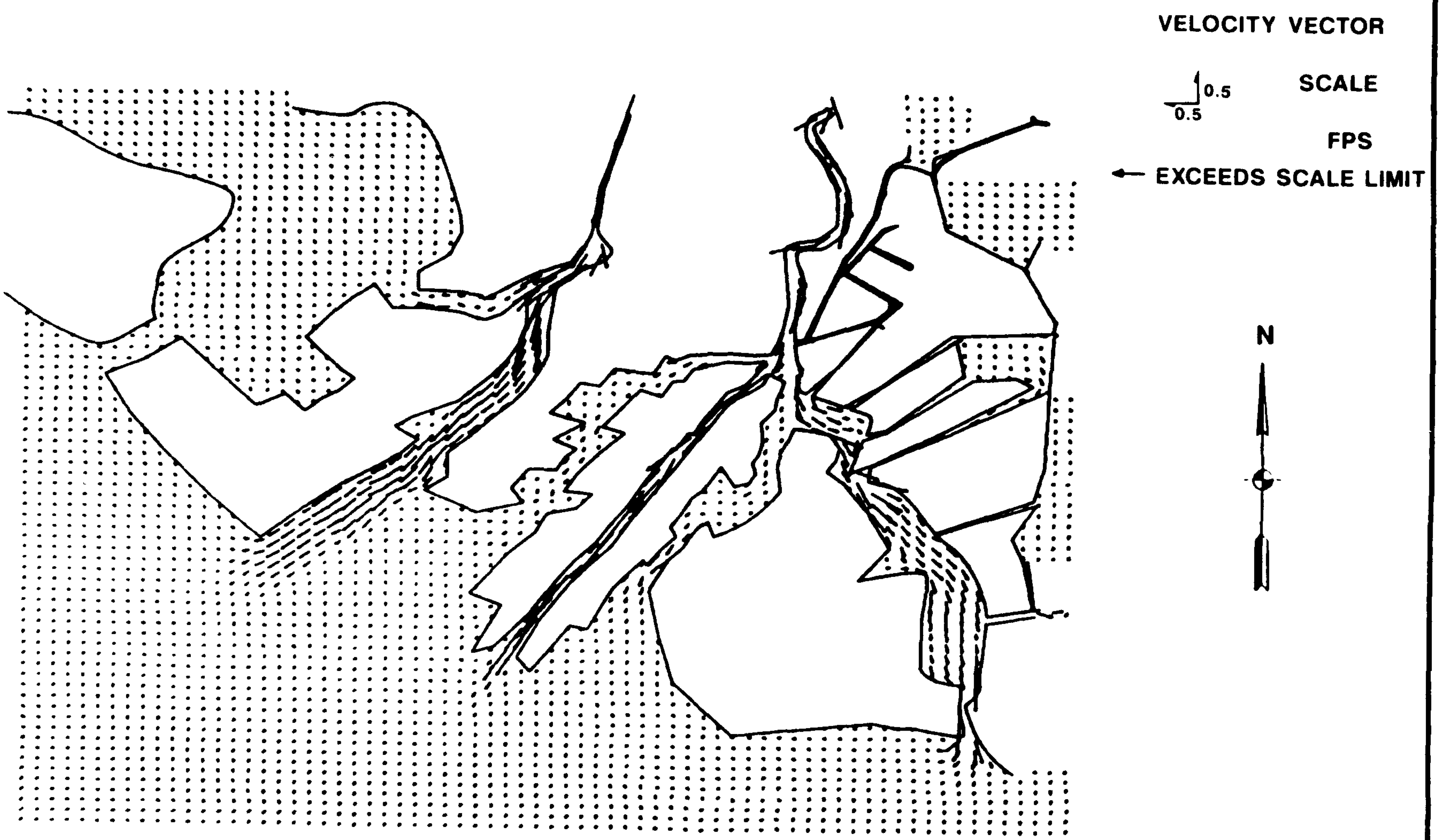
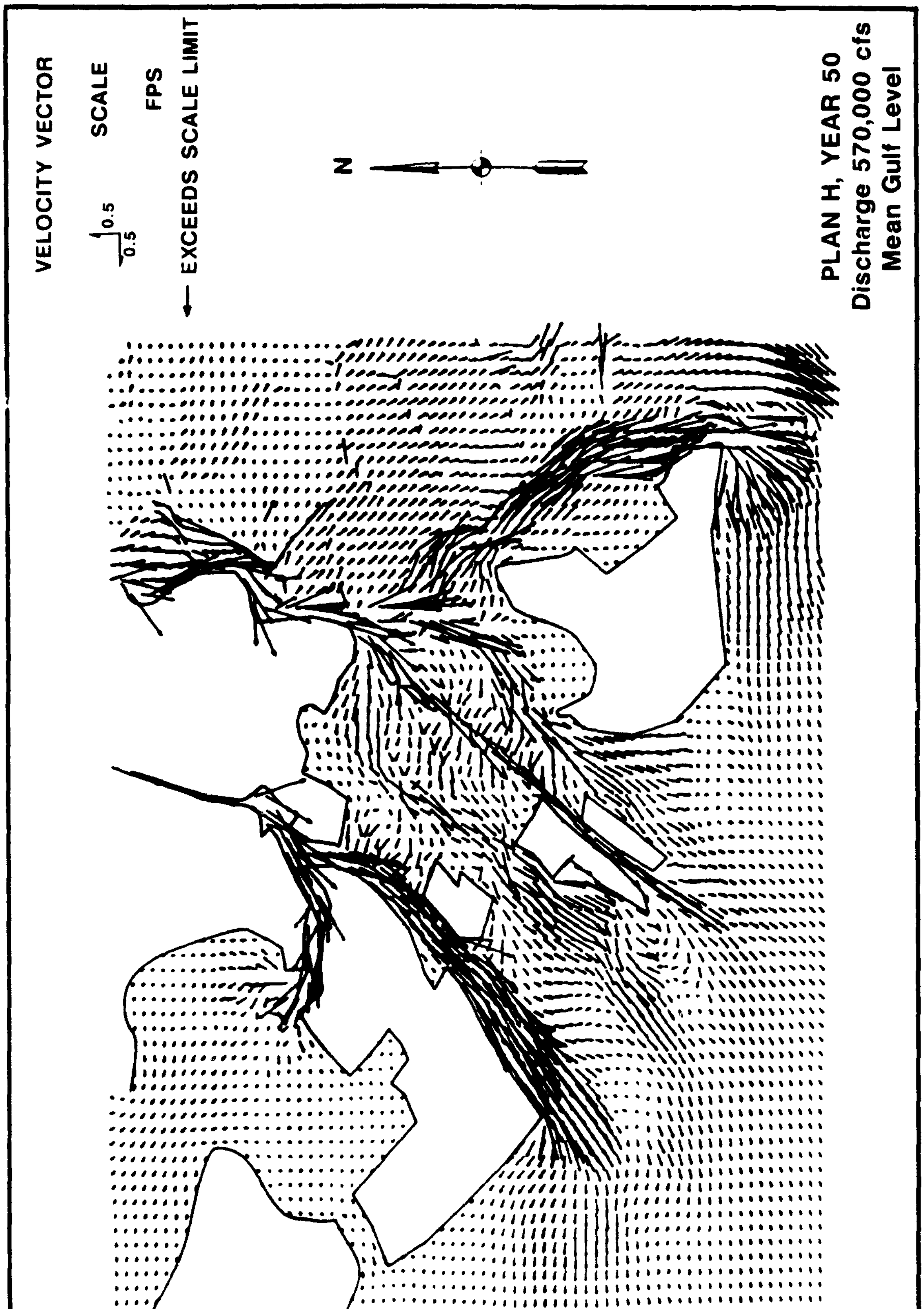
PLAN G, YEAR 50
Discharge 78,000 cfs
Mean Gulf Level



PLAN G, YEAR 50
Discharge 78,000 cfs
High Gulf Level

PLATE 30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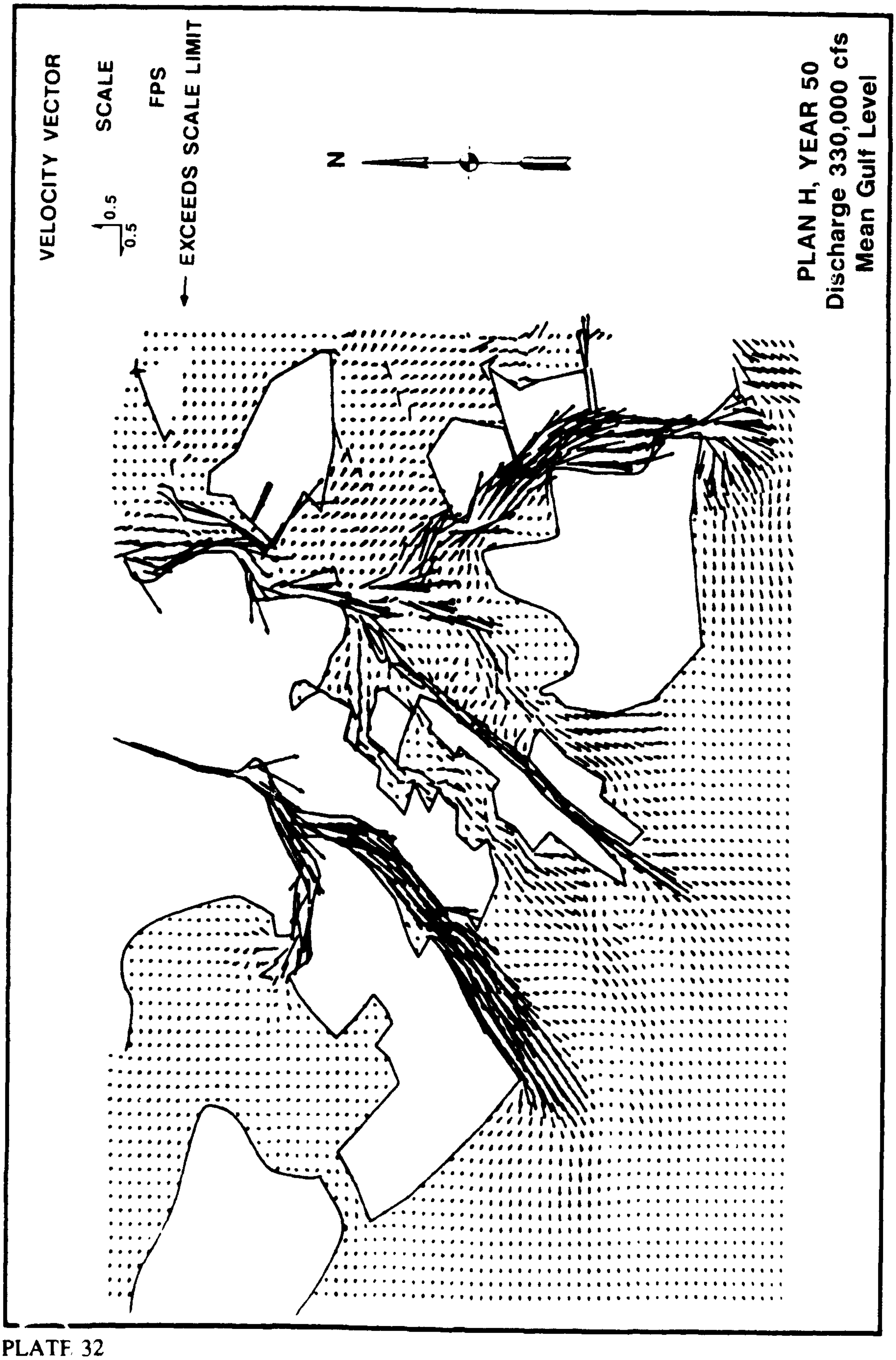
PLAN H, YEAR 50
Discharge 570,000 cfs
Mean Gulf Level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PLAN H, YEAR 50
Discharge 330,000 cfs
Mean Gulf Level

PLATE 32

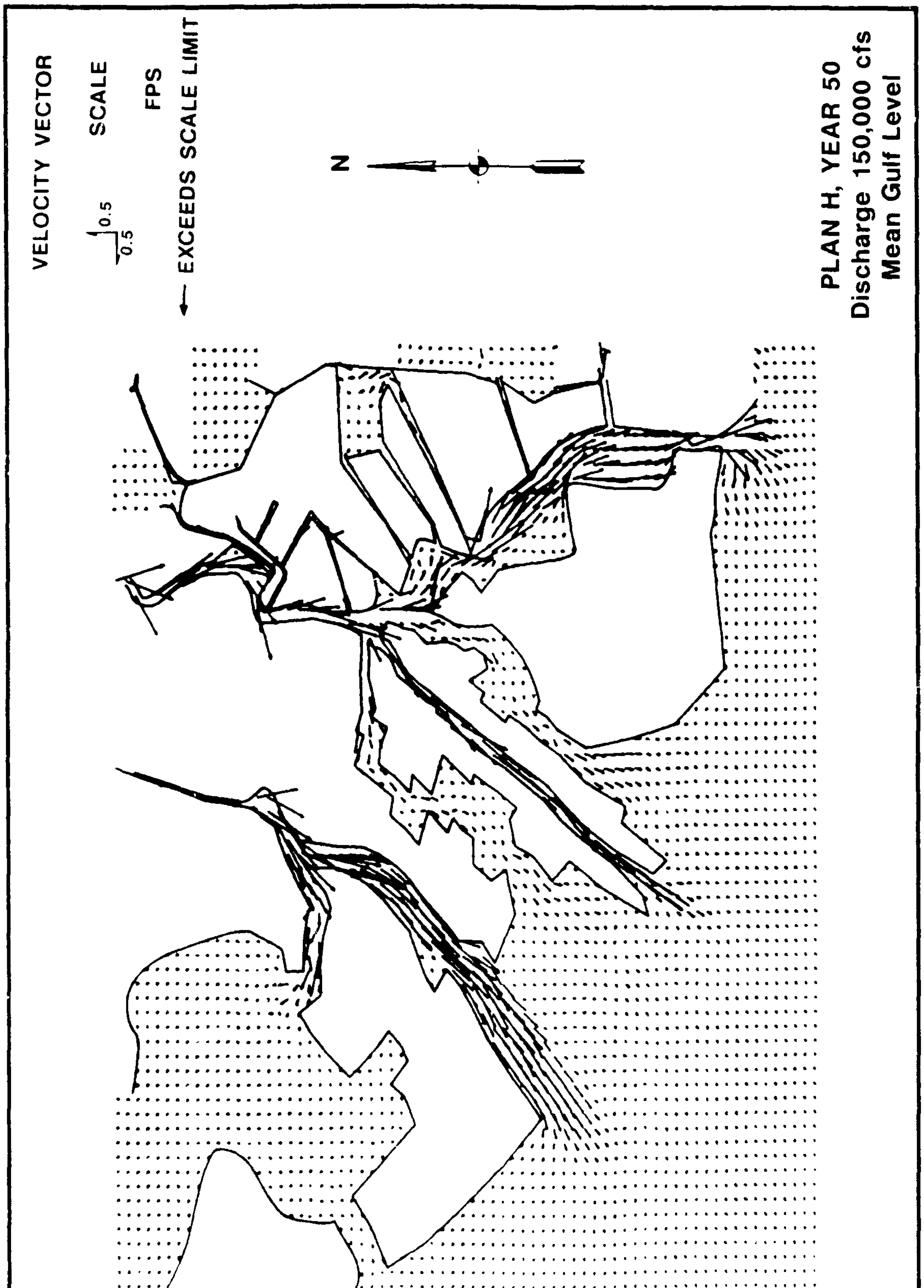
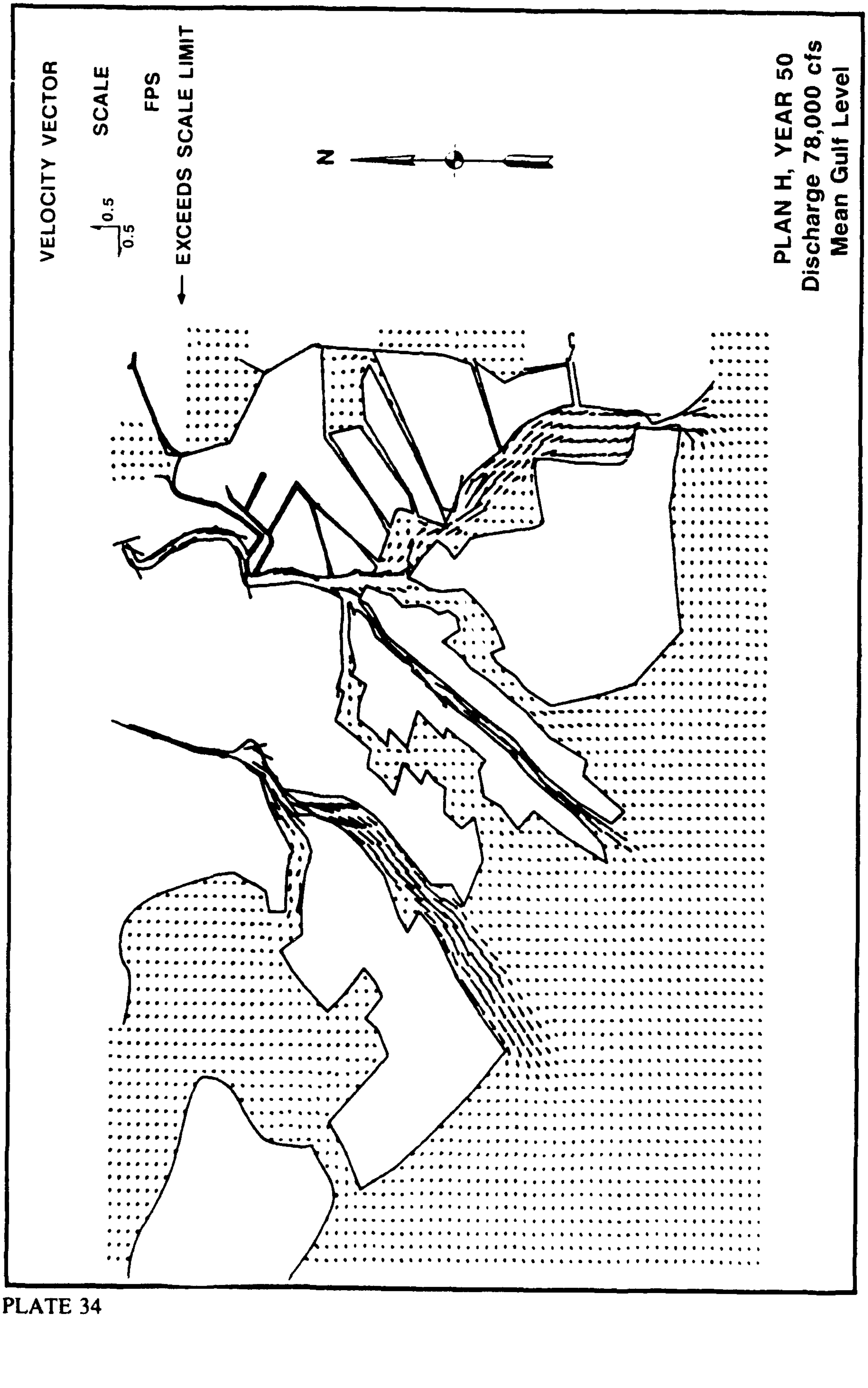

VELOCITY VECTOR
0.5
0.5
SCALE
FPS
EXCEEDS SCALE LIMIT
N
PLAN H, YEAR 50
Discharge 150,000 cfs
Mean Gulf Level

PLATE 33


VELOCITY VECTOR
0.5
0.5
SCALE
FPS
EXCEEDS SCALE LIMIT
N
PLAN H, YEAR 50
Discharge 78,000 cfs
Mean Gulf Level

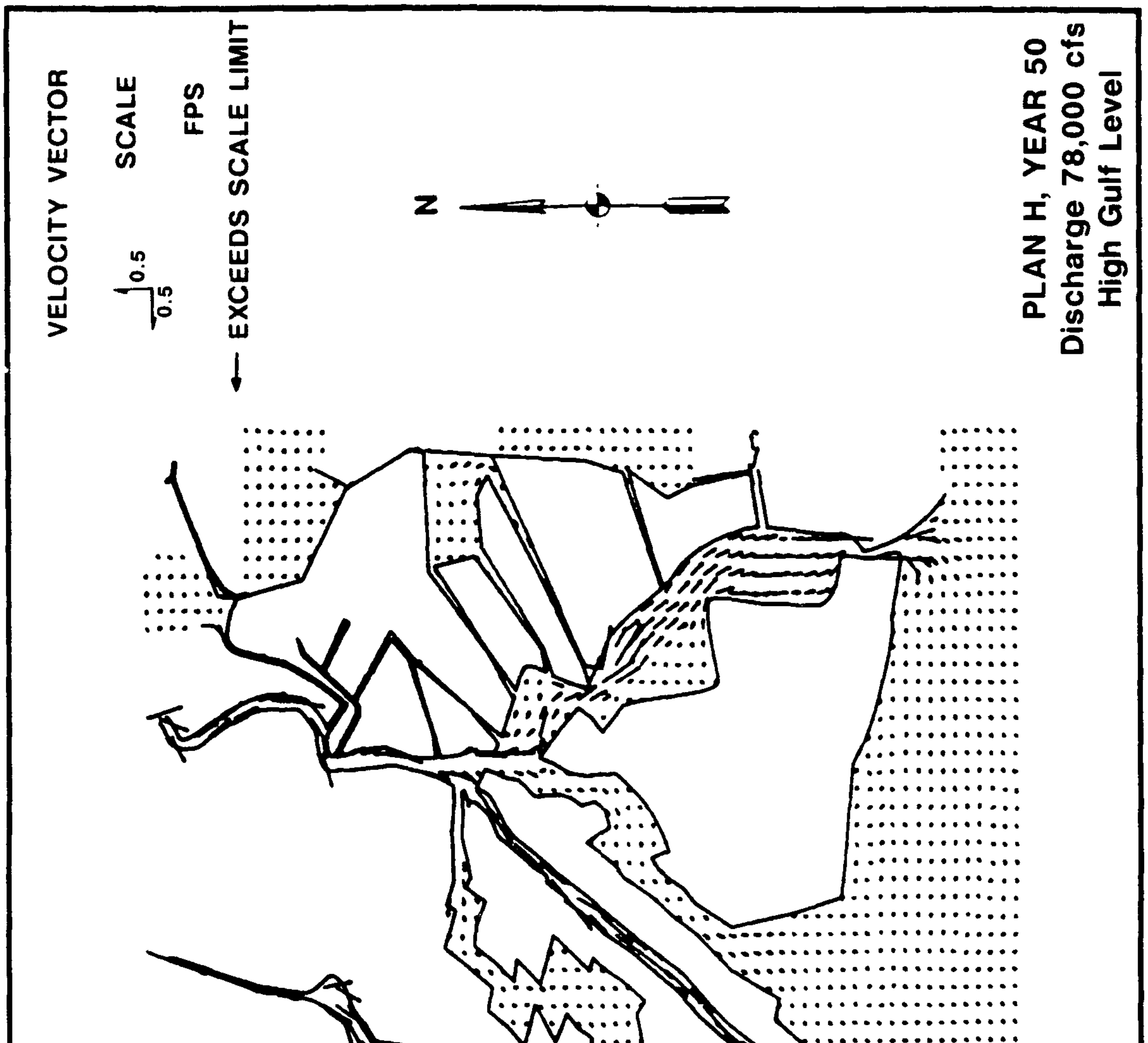

VELOCITY VECTOR
0.5
0.5
SCALE
FPS
EXCEEDS SCALE LIMIT
N
PLAN H, YEAR 50
Discharge 78,000 cfs
High Gulf Level

PLATE 35

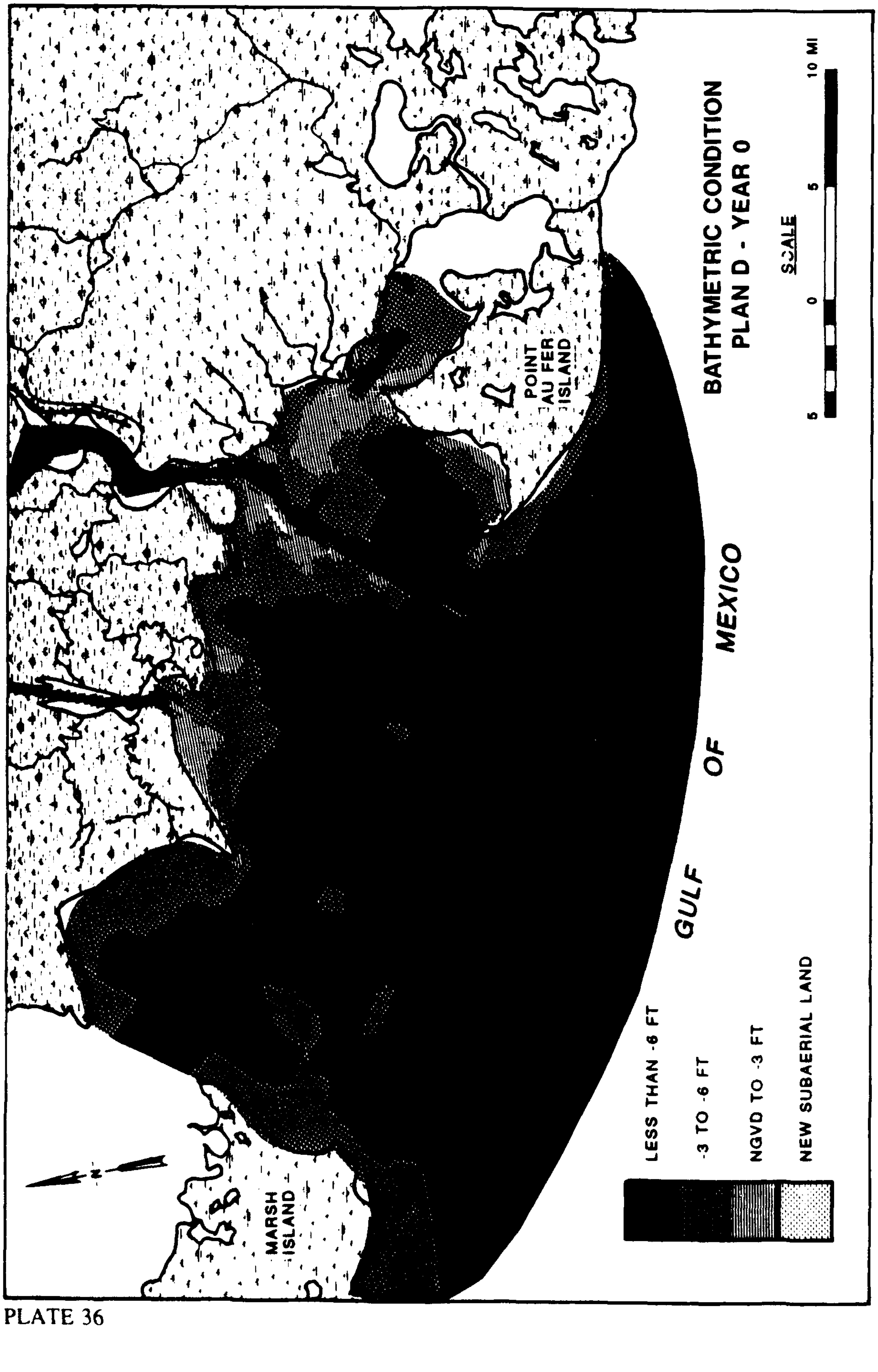
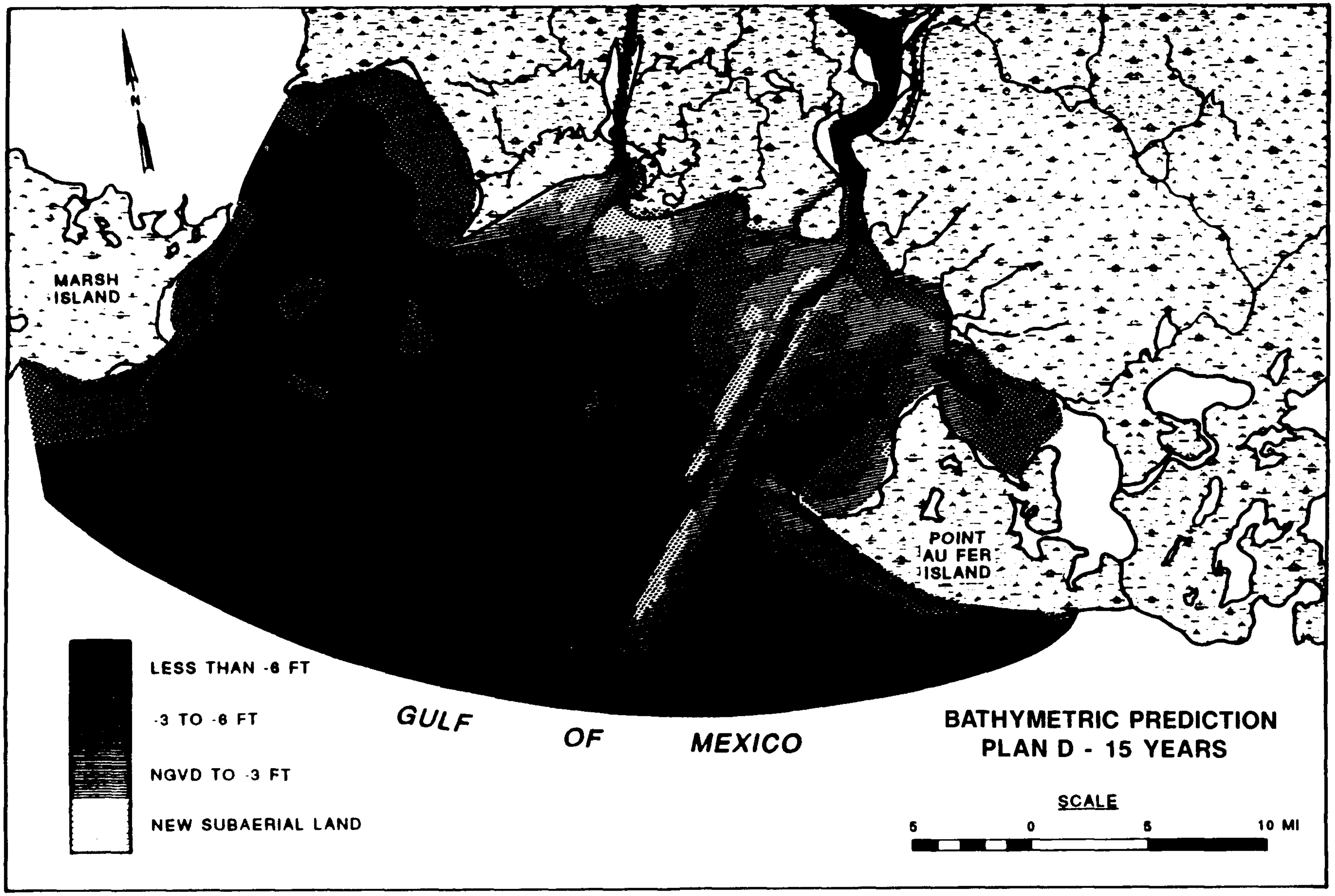

BATHYMETRIC CONDITION
PLAN D - YEAR 0
SCALE
5 0 5 10 MI
GULF OF MEXICO
POINT AU FER ISLAND
MARSH ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 36


N
MARSH ISLAND
POINT AU FER ISLAND
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND
GULF OF MEXICO
BATHYMETRIC PREDICTION
PLAN D - 15 YEARS
SCALE
5 0 5 10 MI

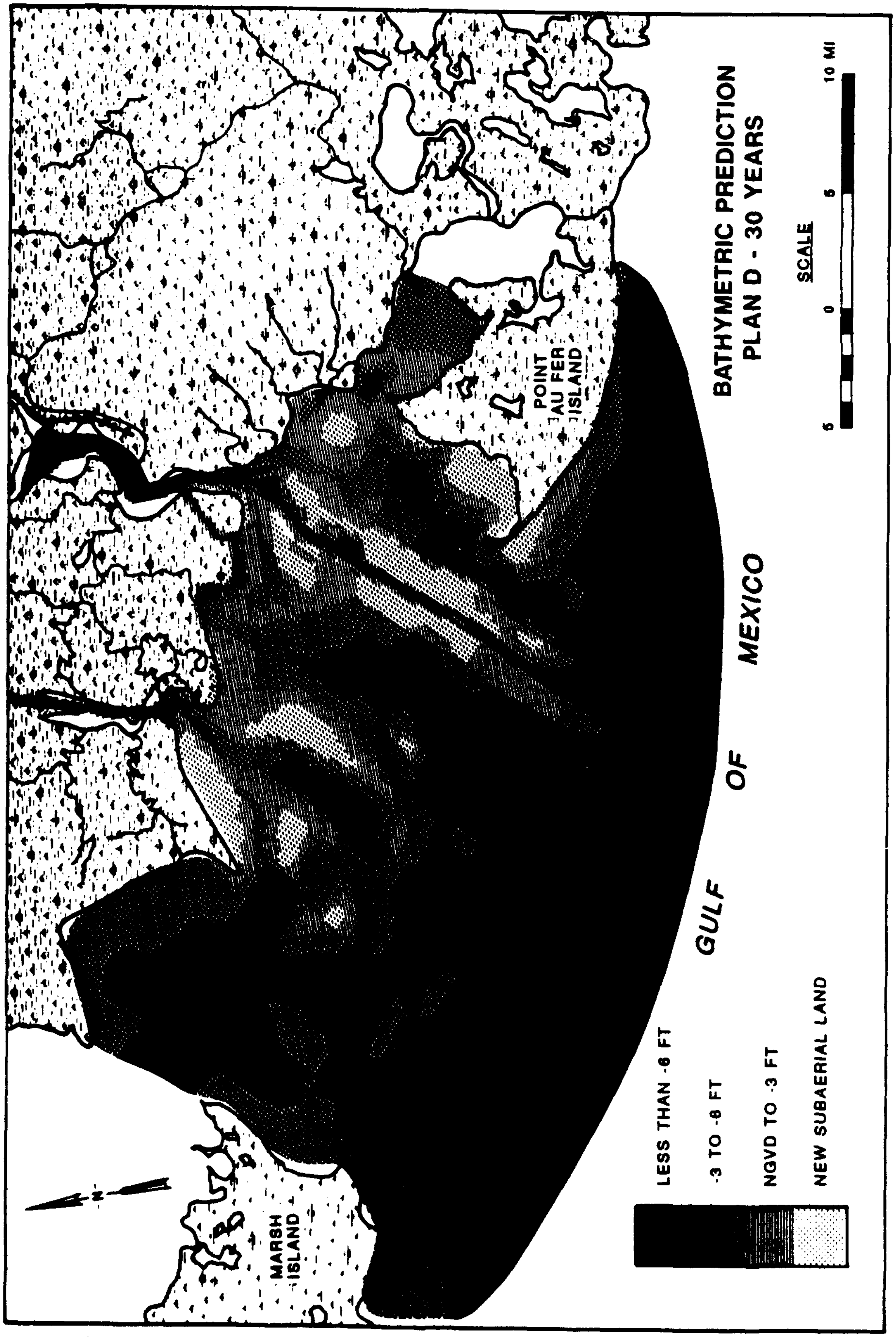

BATHYMETRIC PREDICTION
PLAN D - 30 YEARS
SCALE
5 0 5 10 MI
GULF OF MEXICO
POINT AU FER ISLAND
MARSH ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 38

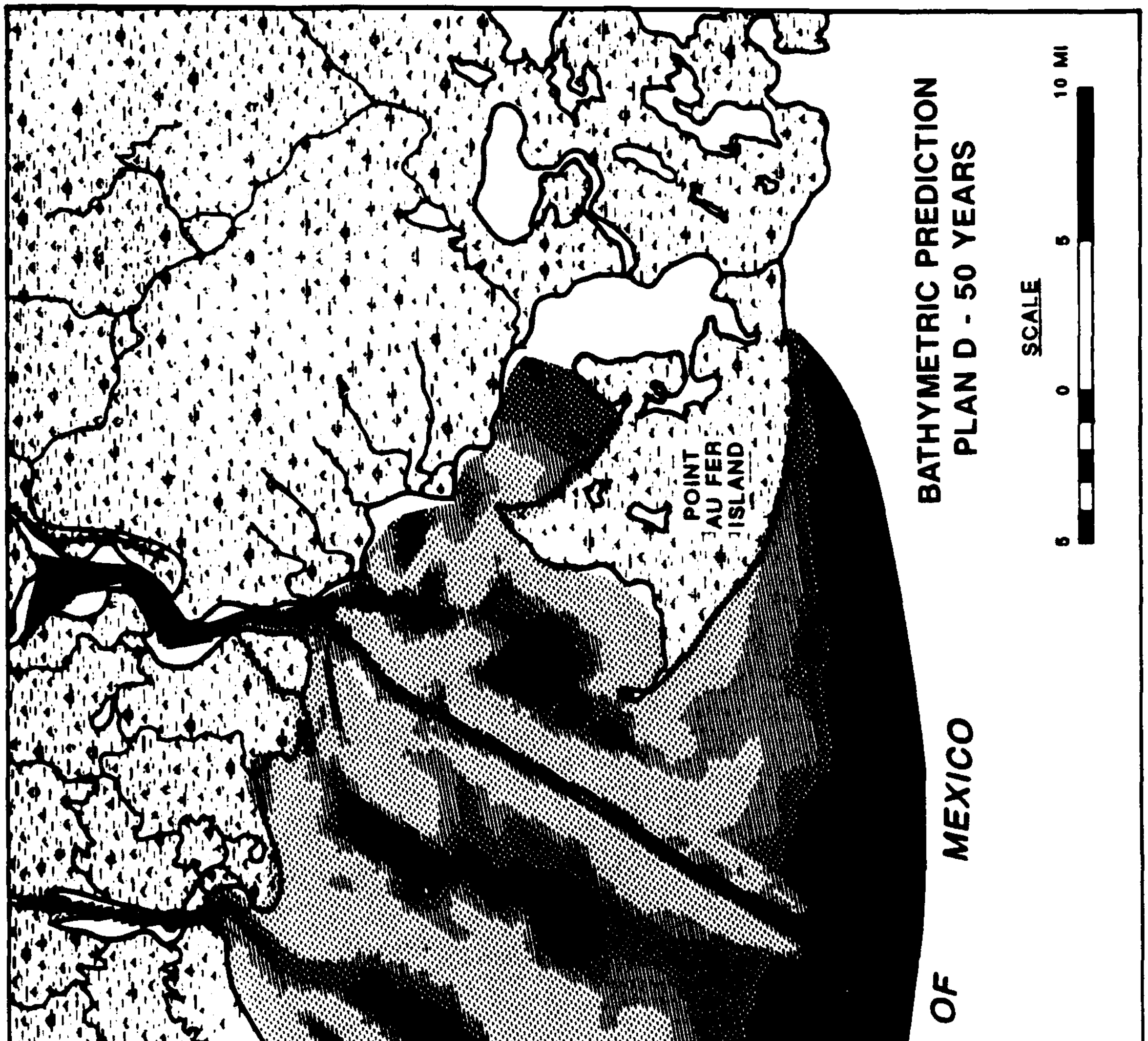

BATHYMETRIC PREDICTION
PLAN D - 50 YEARS
SCALE
5 0 5 10 MI
GULF OF MEXICO
POINT AU FER ISLAND
MARSH ISLAND
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 39

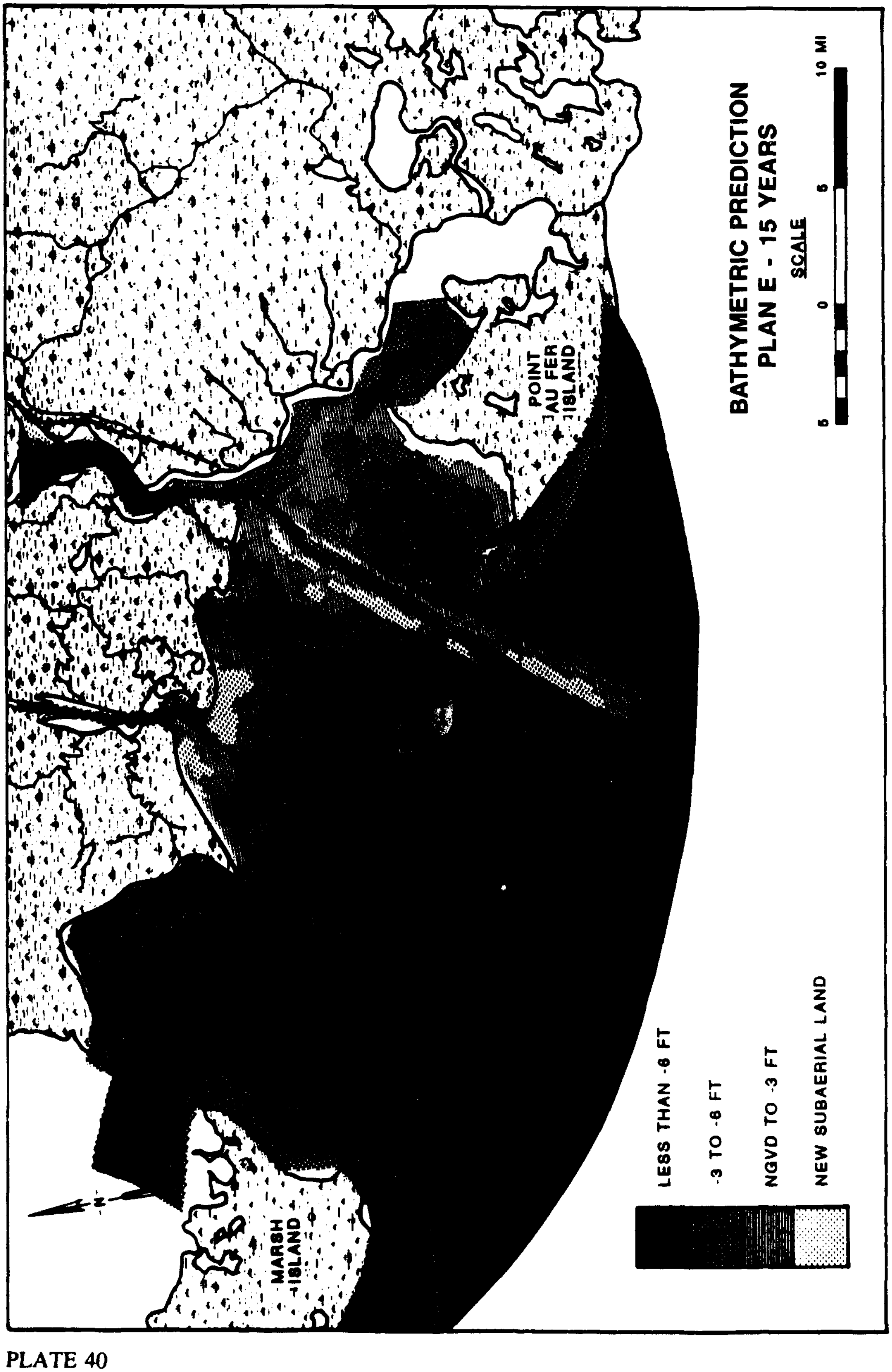
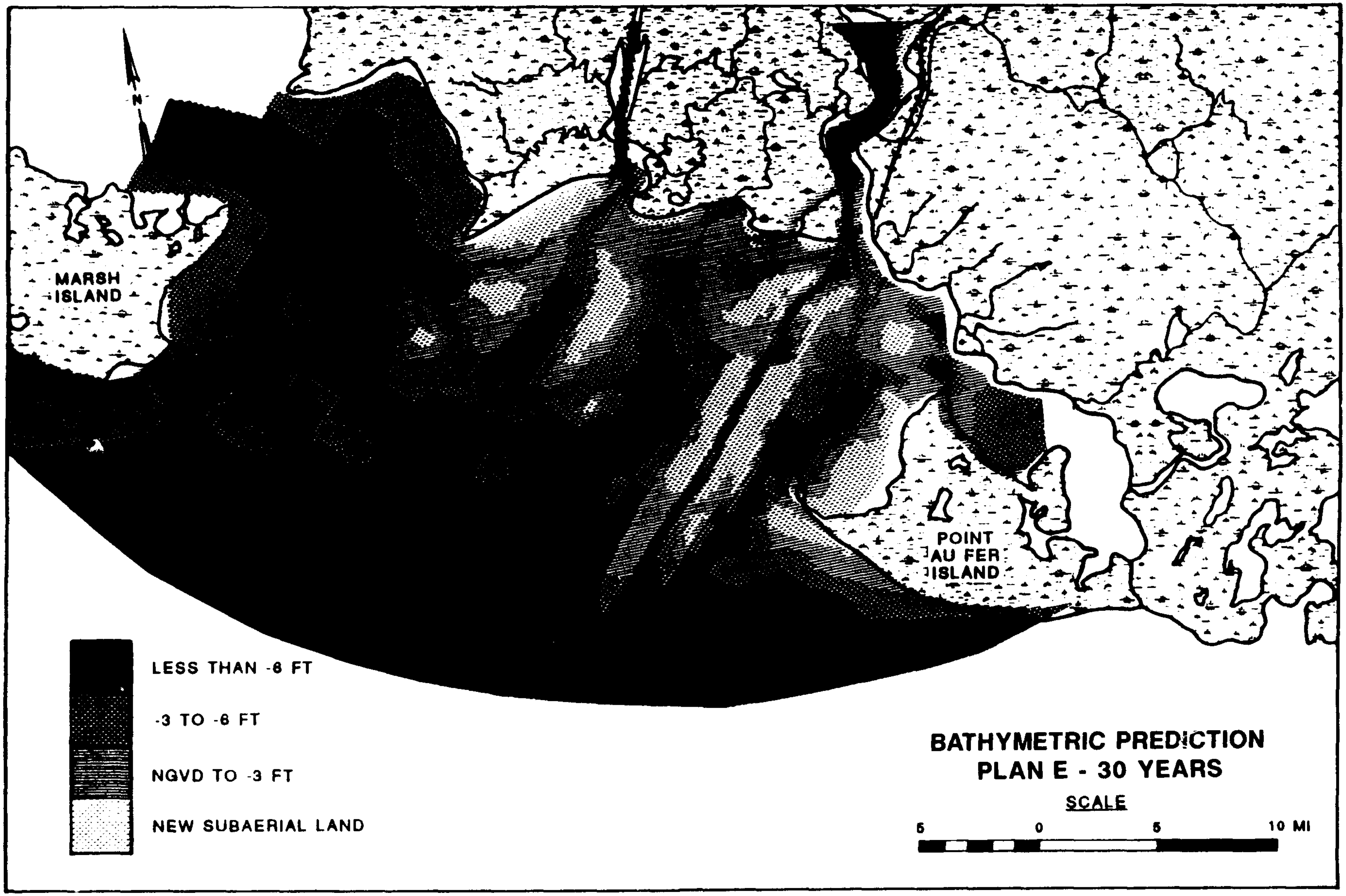

BATHYMETRIC PREDICTION
PLAN E - 15 YEARS
SCALE
5 0 5 10 MI
POINT AU FER ISLAND
MARSH ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 40


N
MARSH ISLAND
POINT AU FER ISLAND
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND
BATHYMETRIC PREDICTION
PLAN E - 30 YEARS
SCALE
5 0 5 10 MI

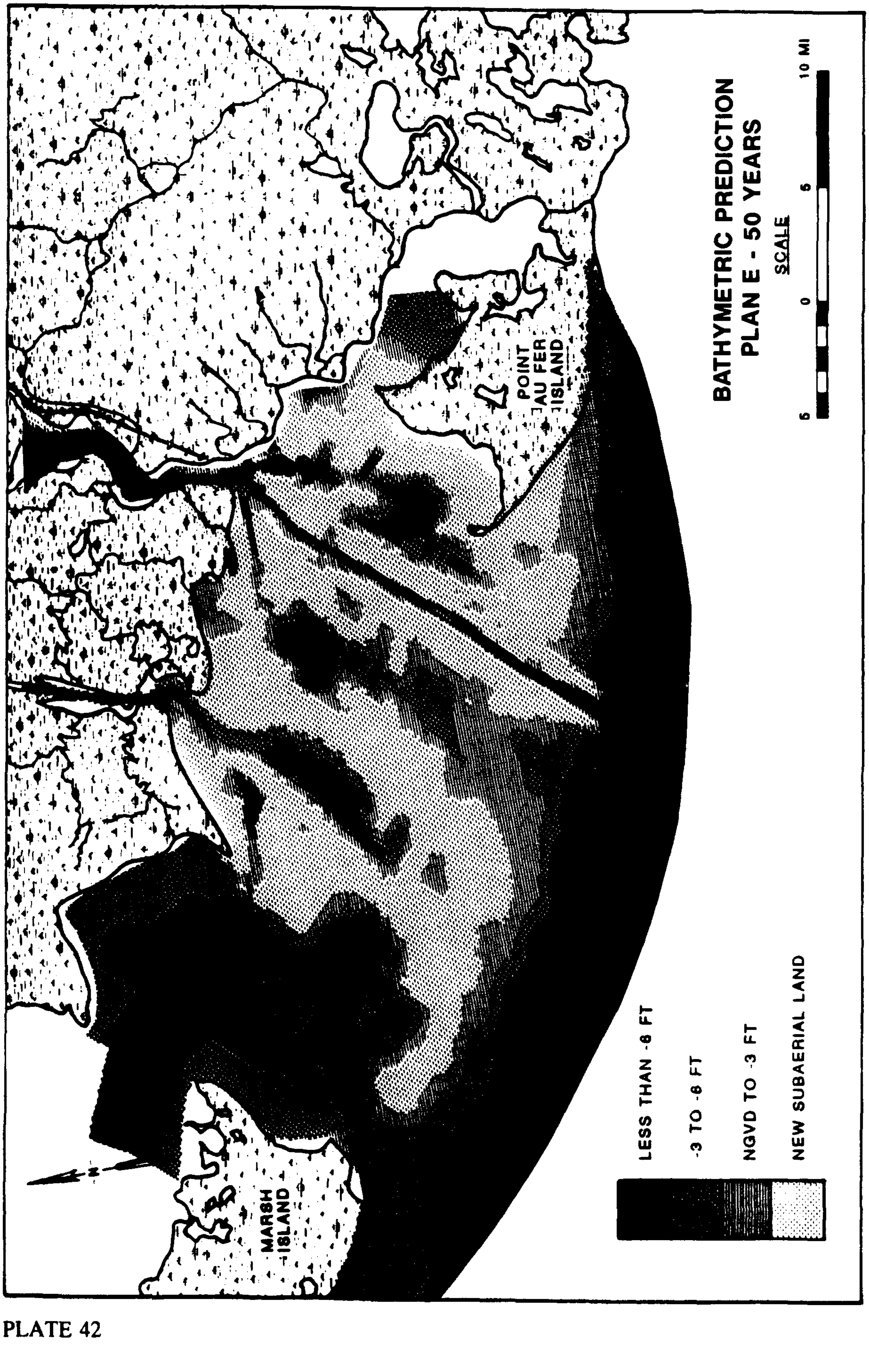

BATHYMETRIC PREDICTION
PLAN E - 50 YEARS
SCALE
5
0
5
10 MI
POINT
AU FER
ISLAND
MARSH
ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 42

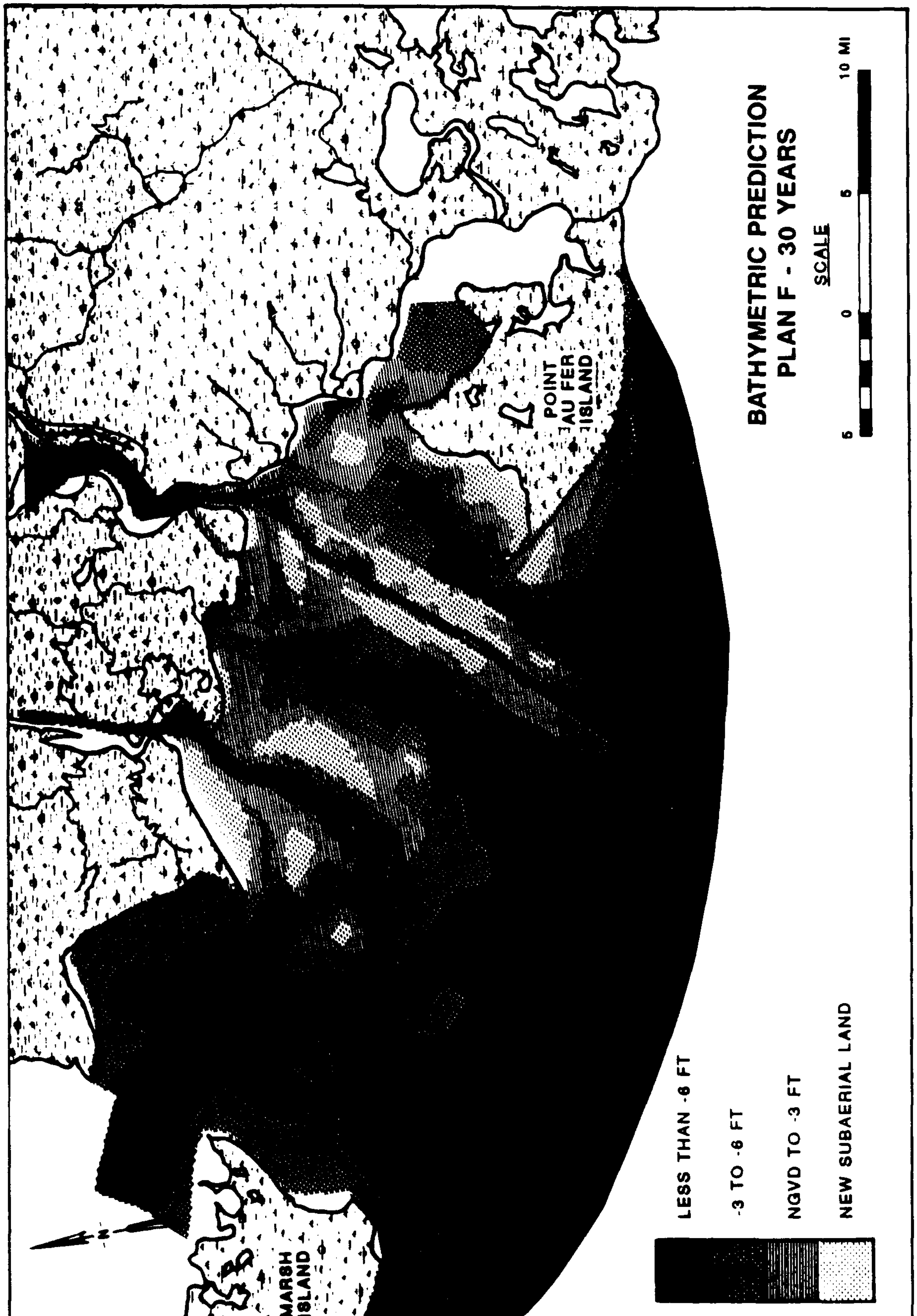

BATHYMETRIC PREDICTION
PLAN F - 30 YEARS
SCALE
5 0 5 10 MI
POINT AU FER ISLAND
MARSH ISLAND
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 43

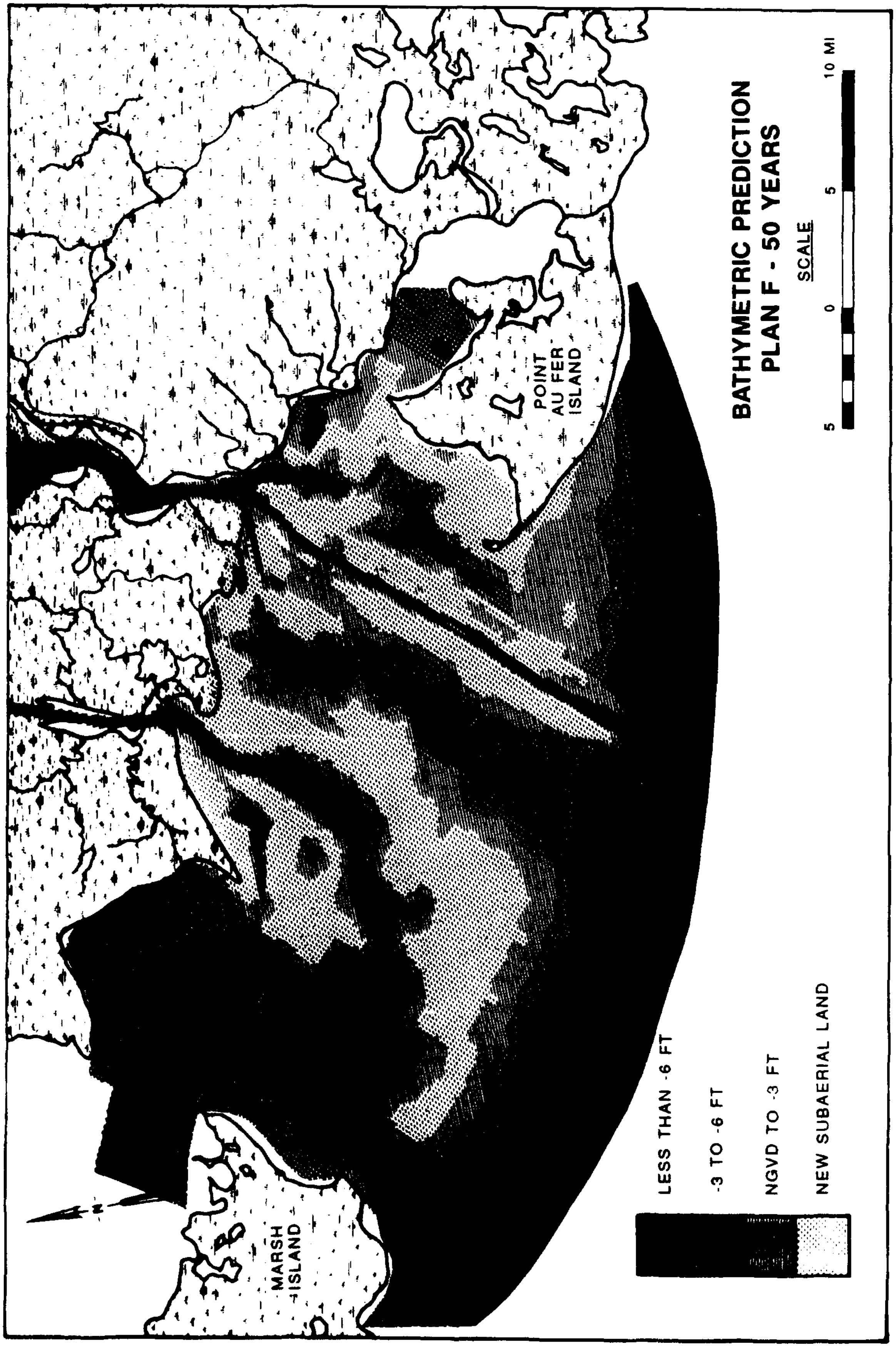

BATHYMETRIC PREDICTION
PLAN F - 50 YEARS
SCALE
5
0
5
10 MI
POINT
AU FER
ISLAND
MARSH
ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 44

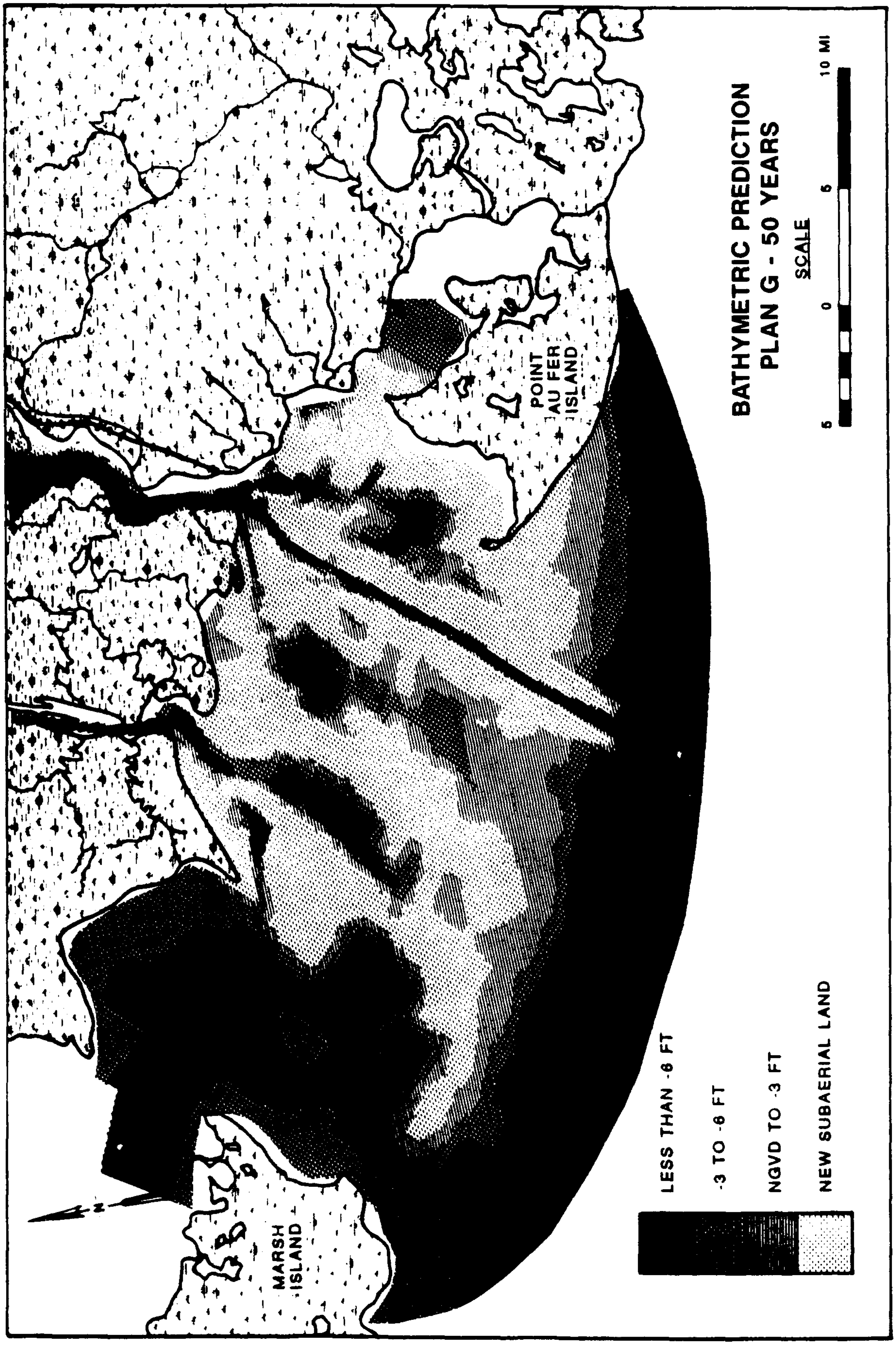

BATHYMETRIC PREDICTION
PLAN G - 50 YEARS
SCALE
5
0
5
10 MI
POINT
AU FER
ISLAND
MARSH
ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 45

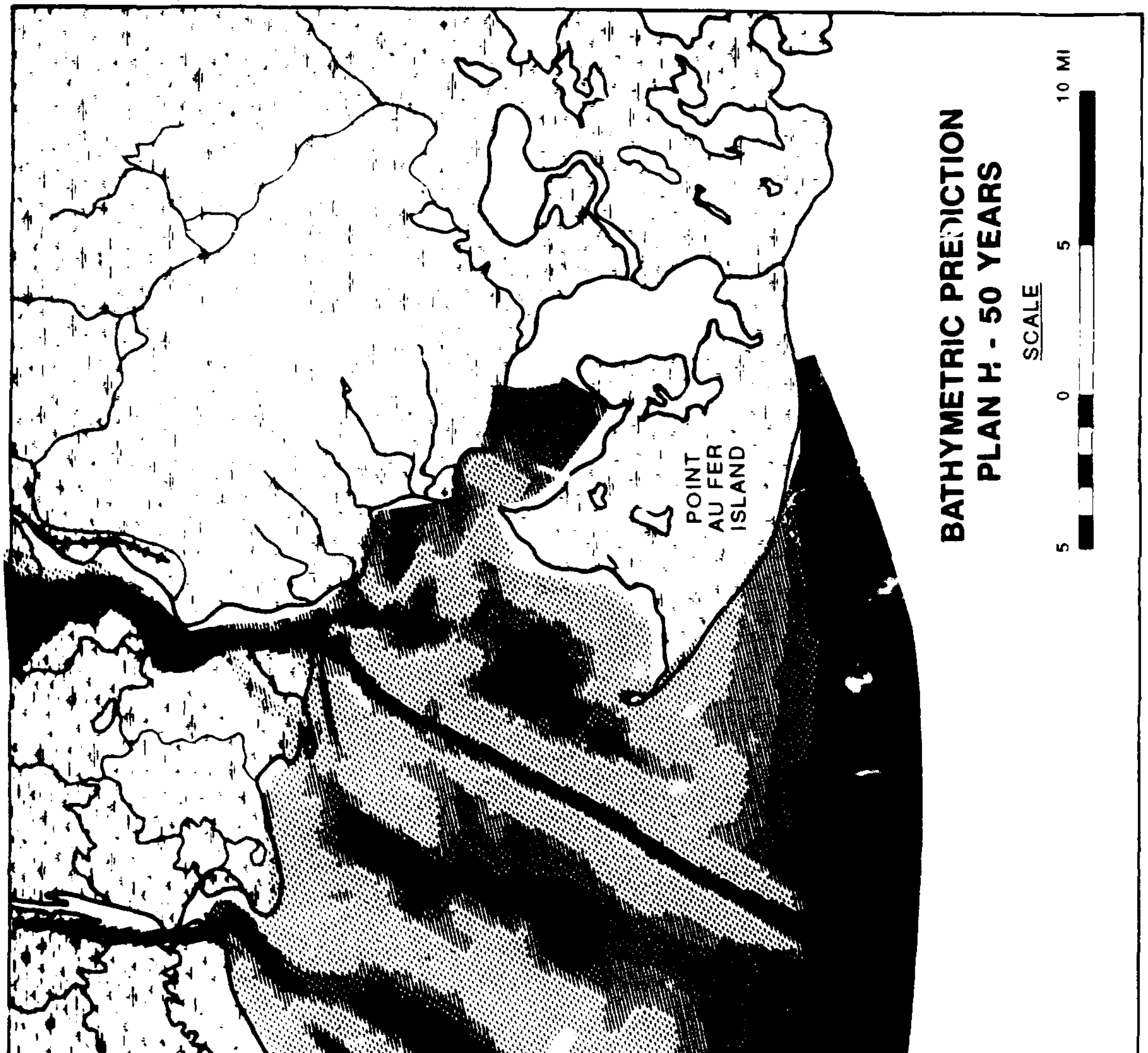
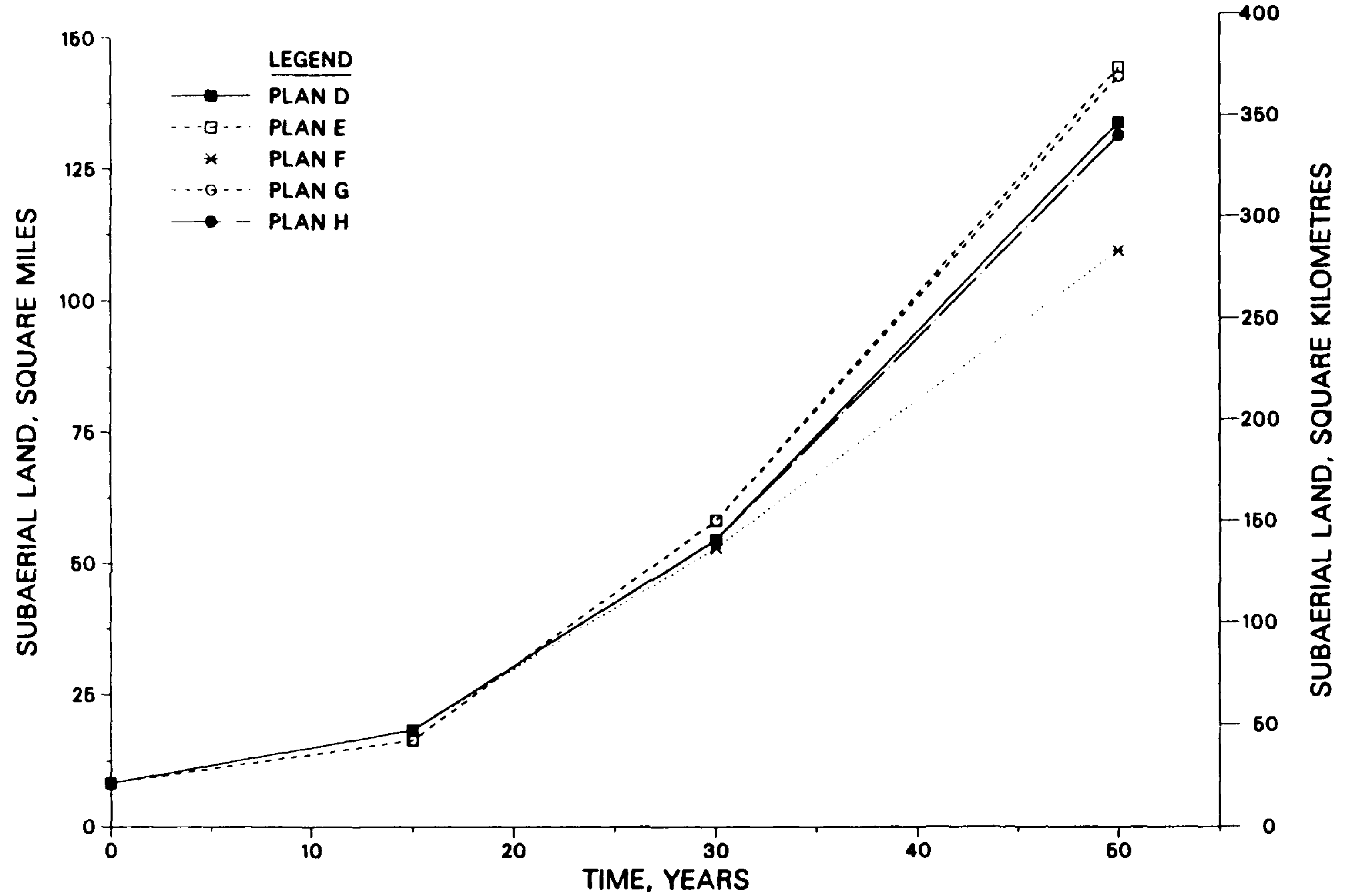

BATHYMETRIC PREDICTION
PLAN H - 50 YEARS
SCALE
5 0 5 10 MI
POINT AU FER ISLAND
MARSH ISLAND
N
LESS THAN -6 FT
-3 TO -6 FT
NGVD TO -3 FT
NEW SUBAERIAL LAND

PLATE 46



SUBAERIAL LAND PREDICTIONS

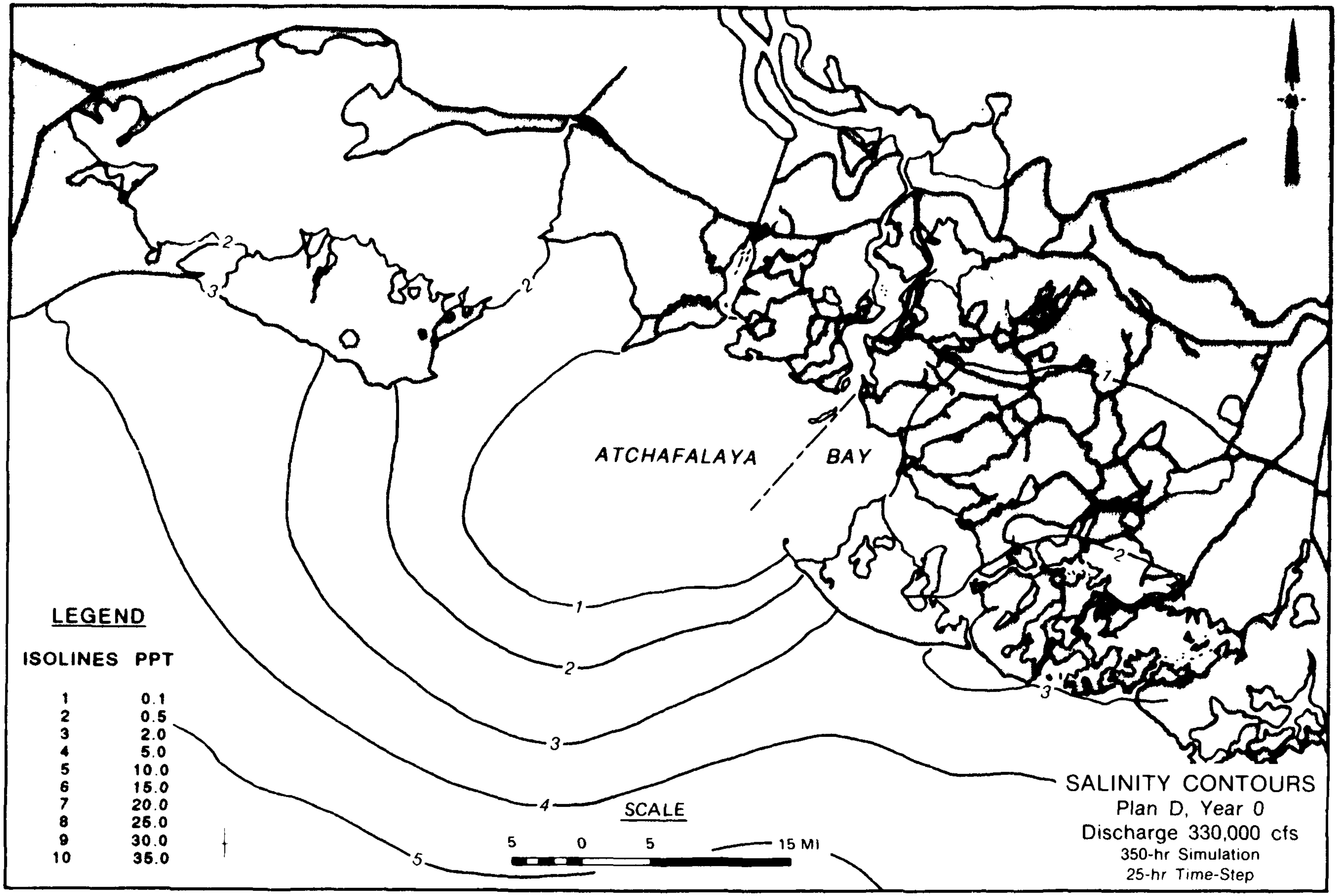
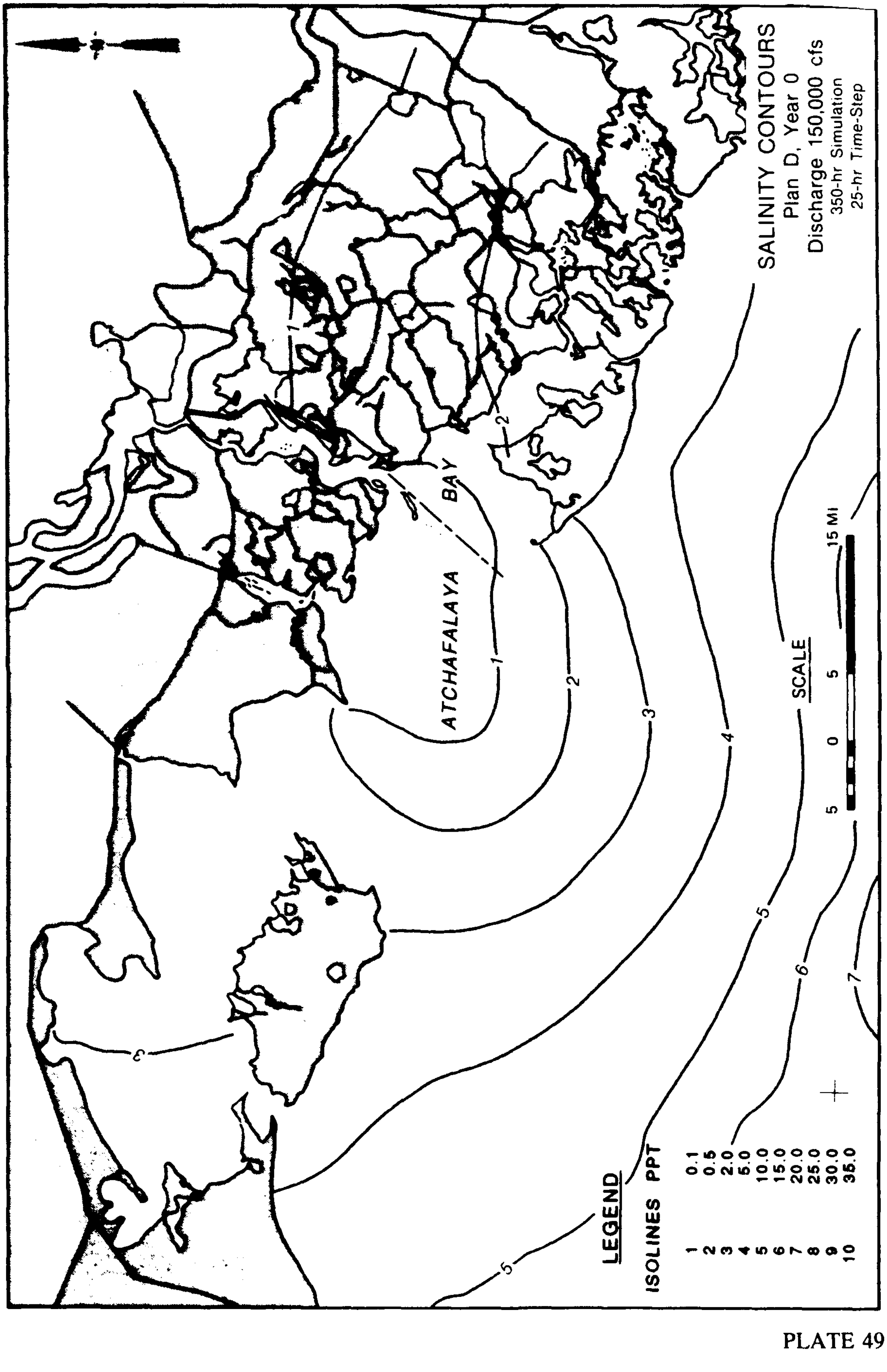

ATCHAFALAYA BAY
1
2
3
4
5
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan D, Year 0
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step

PLATE 48


SALINITY CONTOURS
Plan D, Year 0
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

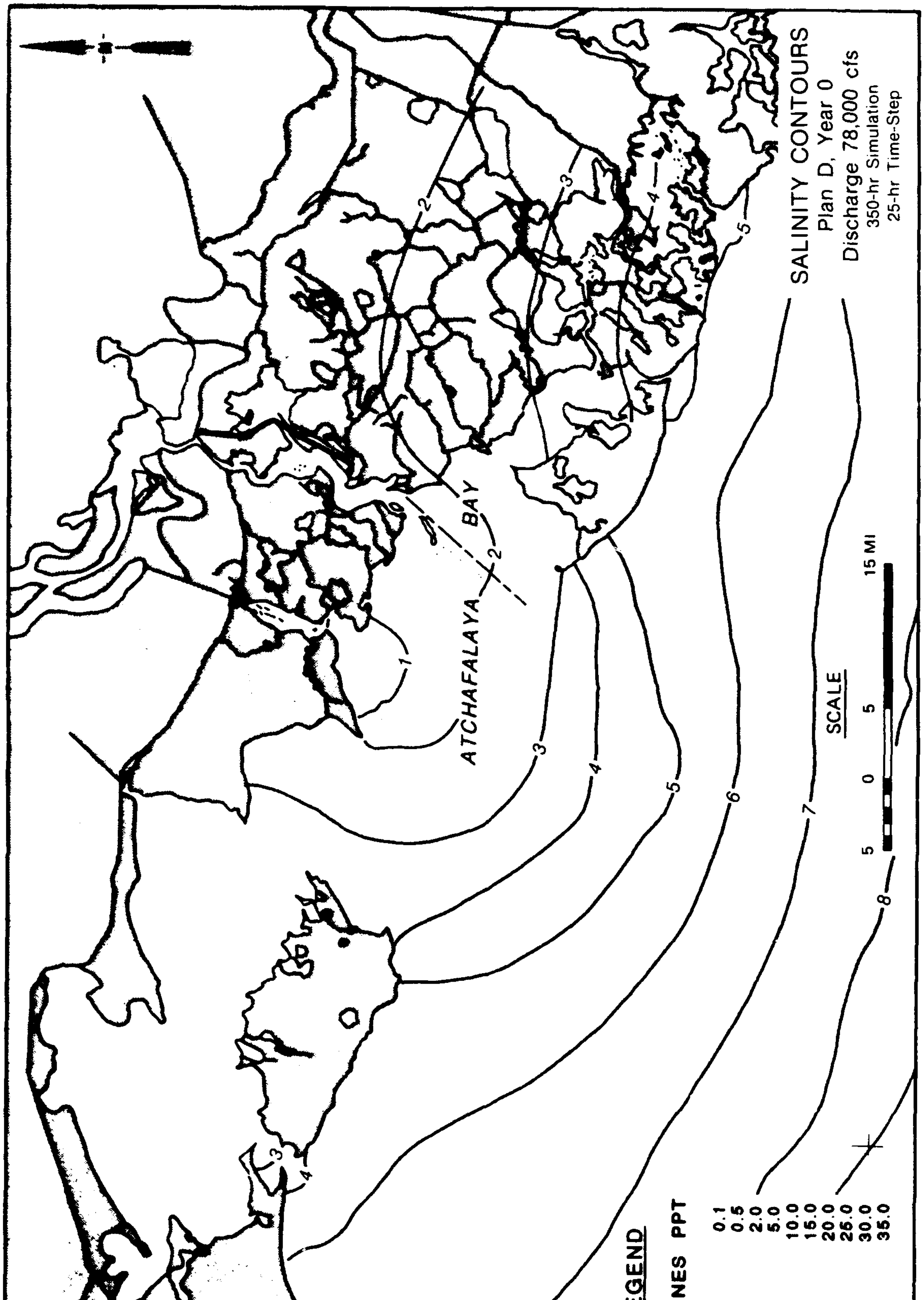
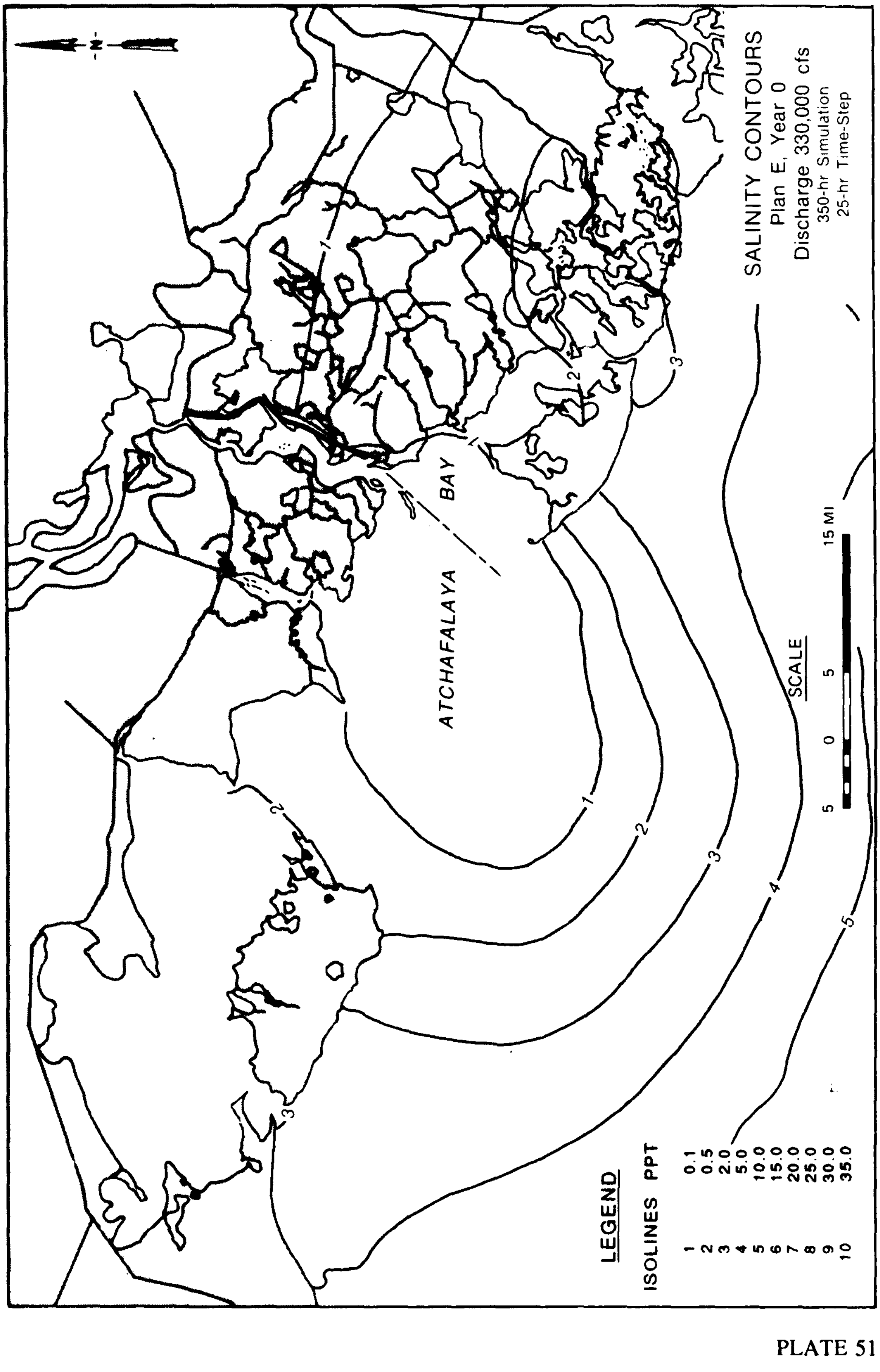

SALINITY CONTOURS
Plan D, Year 0
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA
BAY
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI

PLATE 50


SALINITY CONTOURS
Plan E, Year 0
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA BAY
N
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

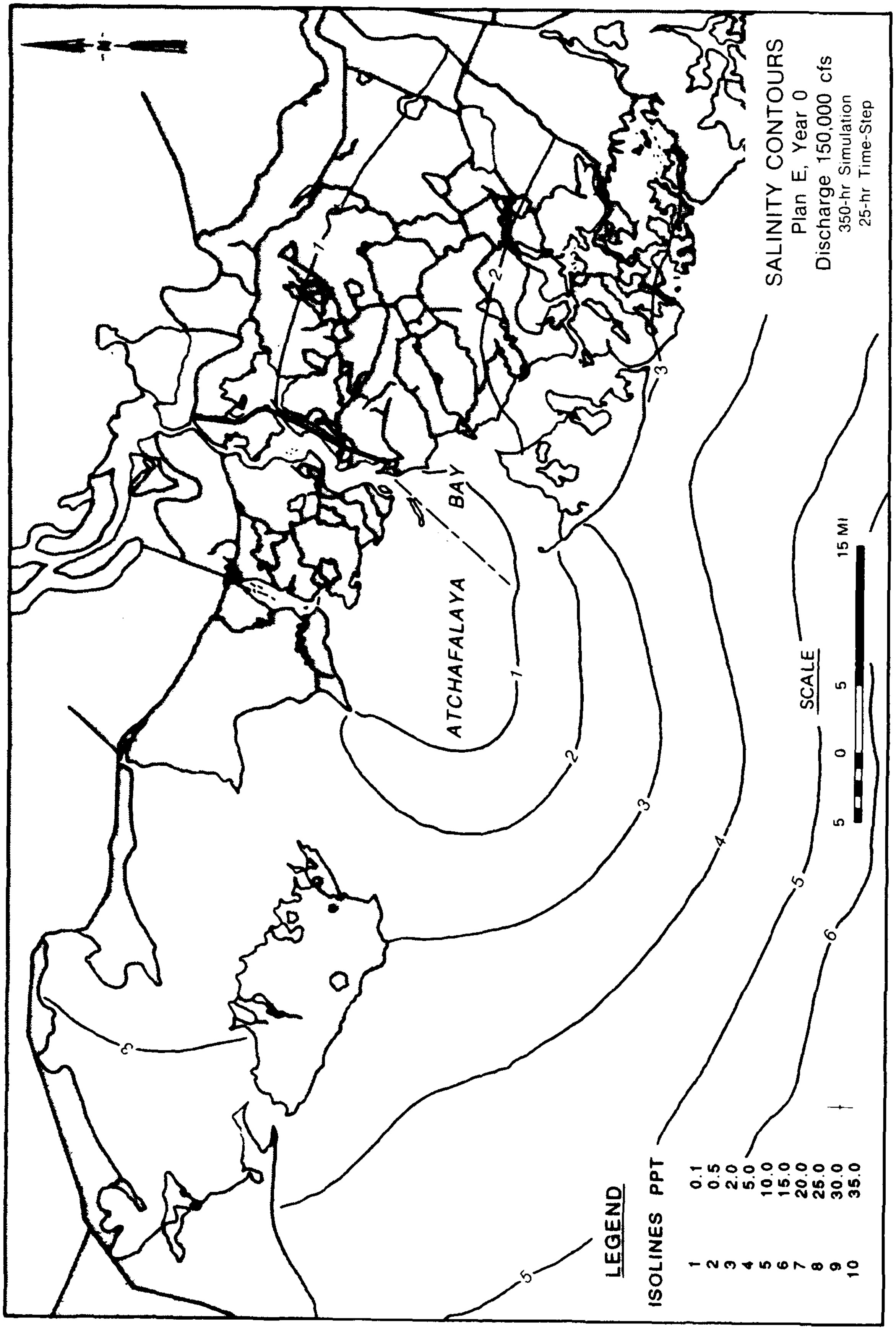
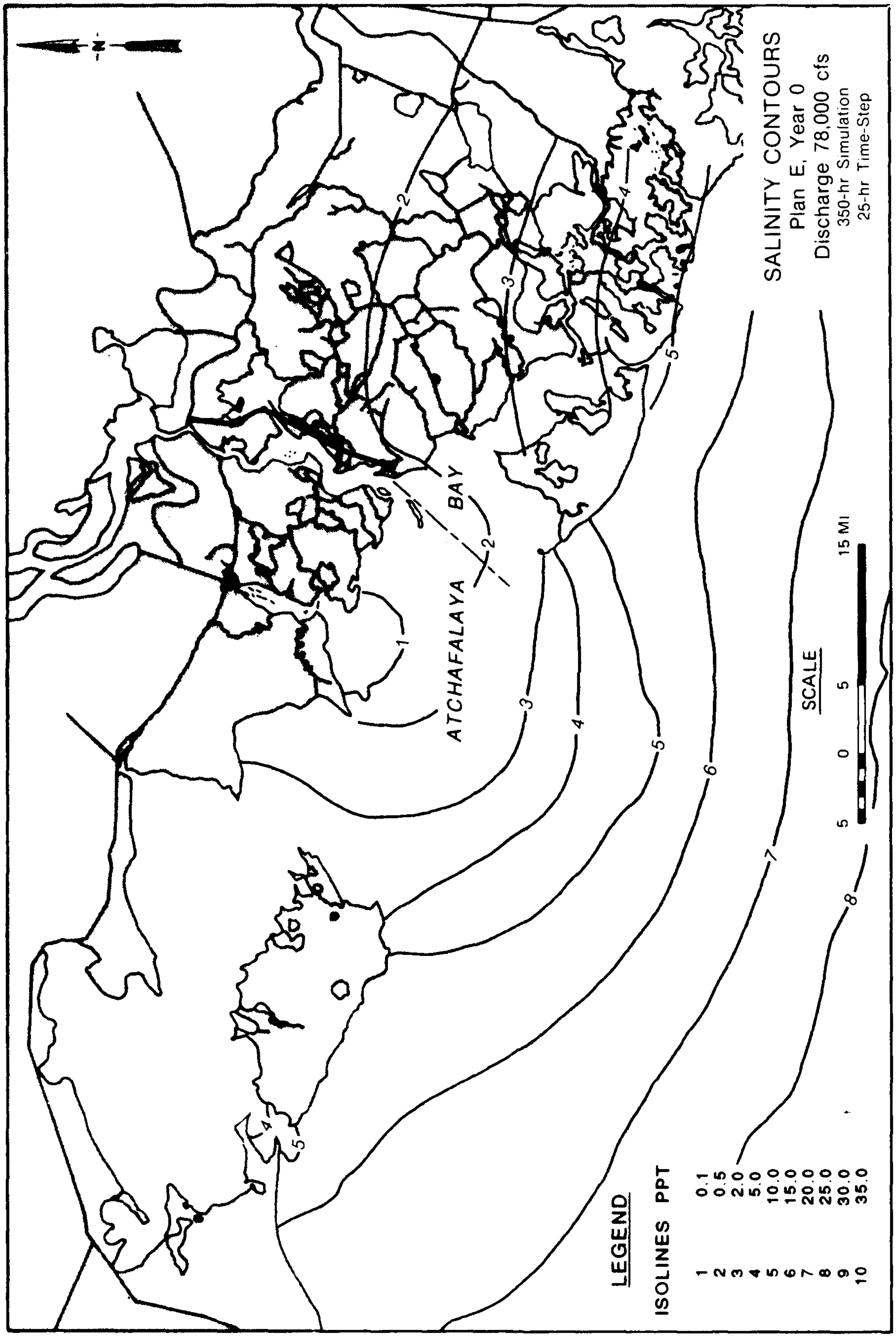
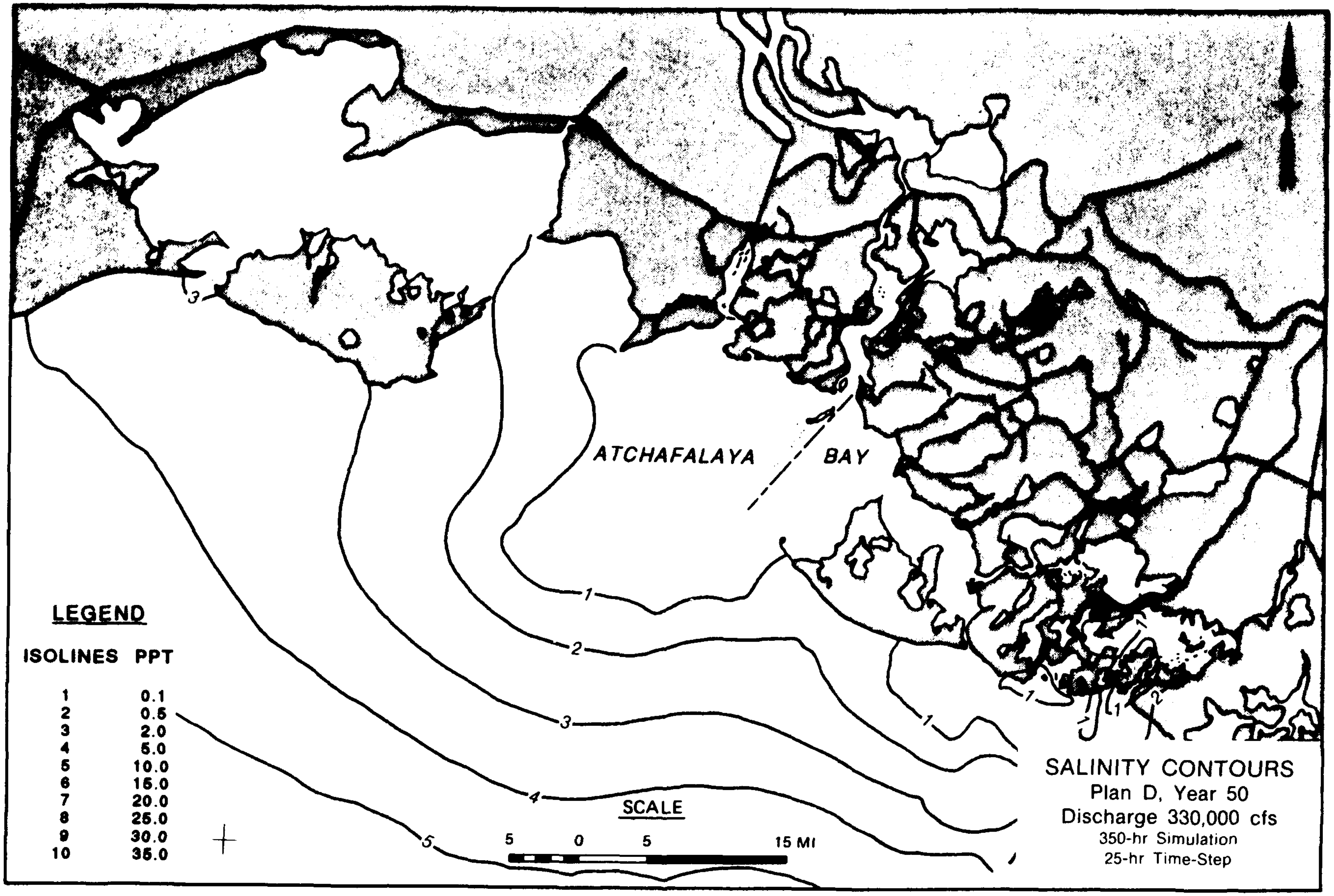
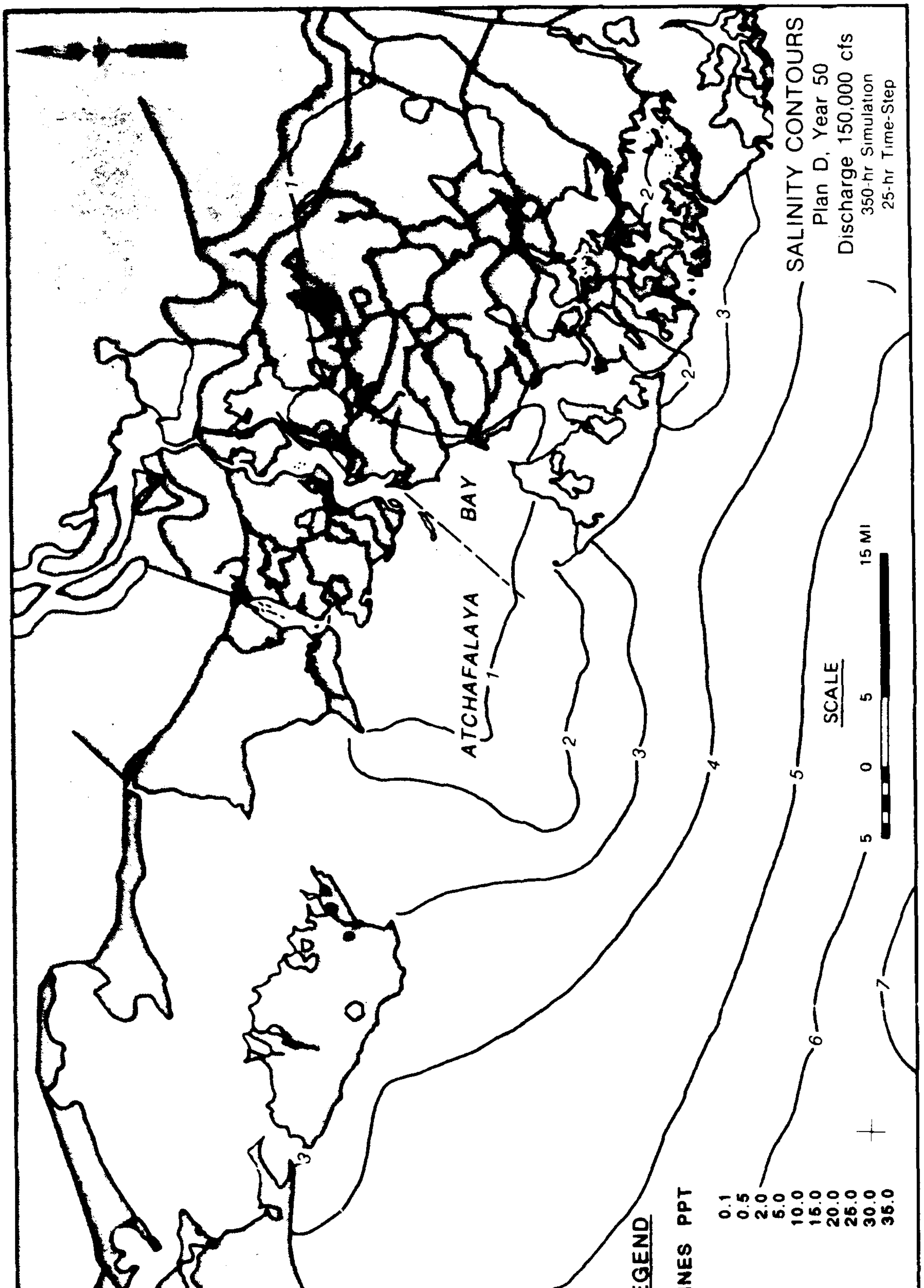
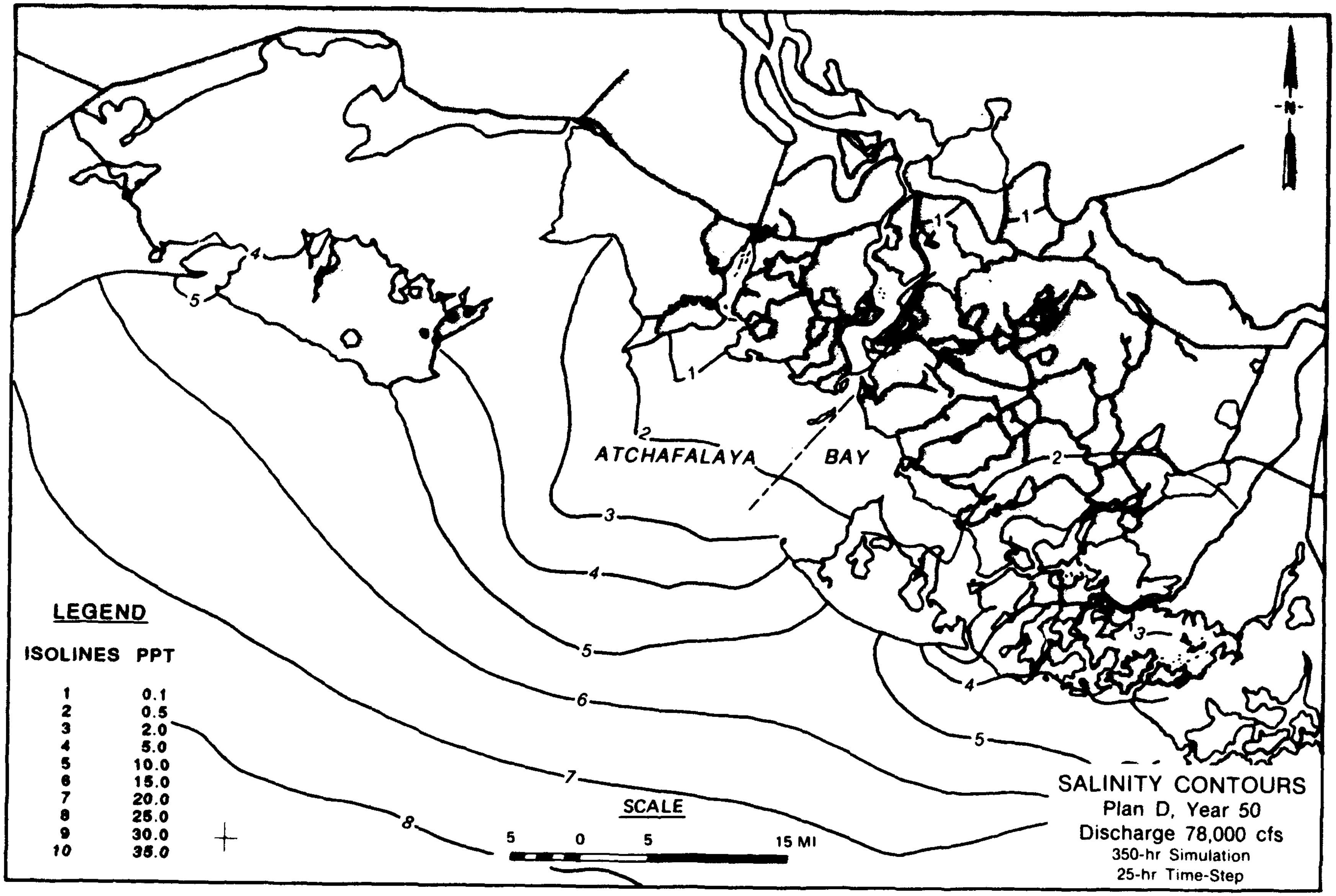

SALINITY CONTOURS
Plan E, Year 0
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

PLATE 52

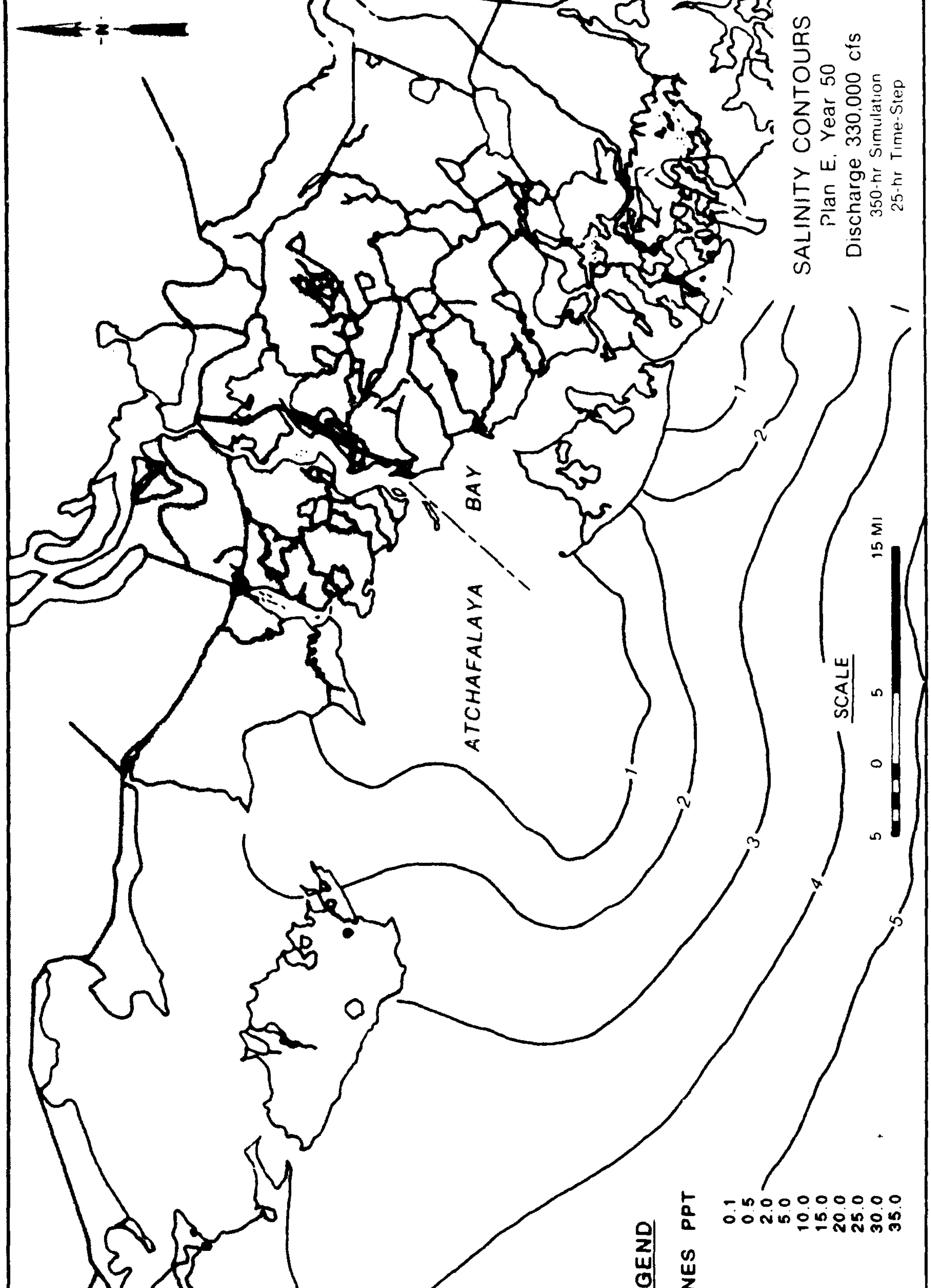

SALINITY CONTOURS
Plan E, Year 0
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
ATCHAFALAYA BAY
SCALE
5 0 5 15 MI
N


ATCHAFALAYA BAY
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan D, Year 50
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step


SALINITY CONTOURS
Plan D, Year 50
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA
BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0



ATCHAFALAYA
BAY
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
N
SALINITY CONTOURS
Plan D, Year 50
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step


N
ATCHAFALAYA BAY
SALINITY CONTOURS
Plan E, Year 50
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
1
2
3
4
5

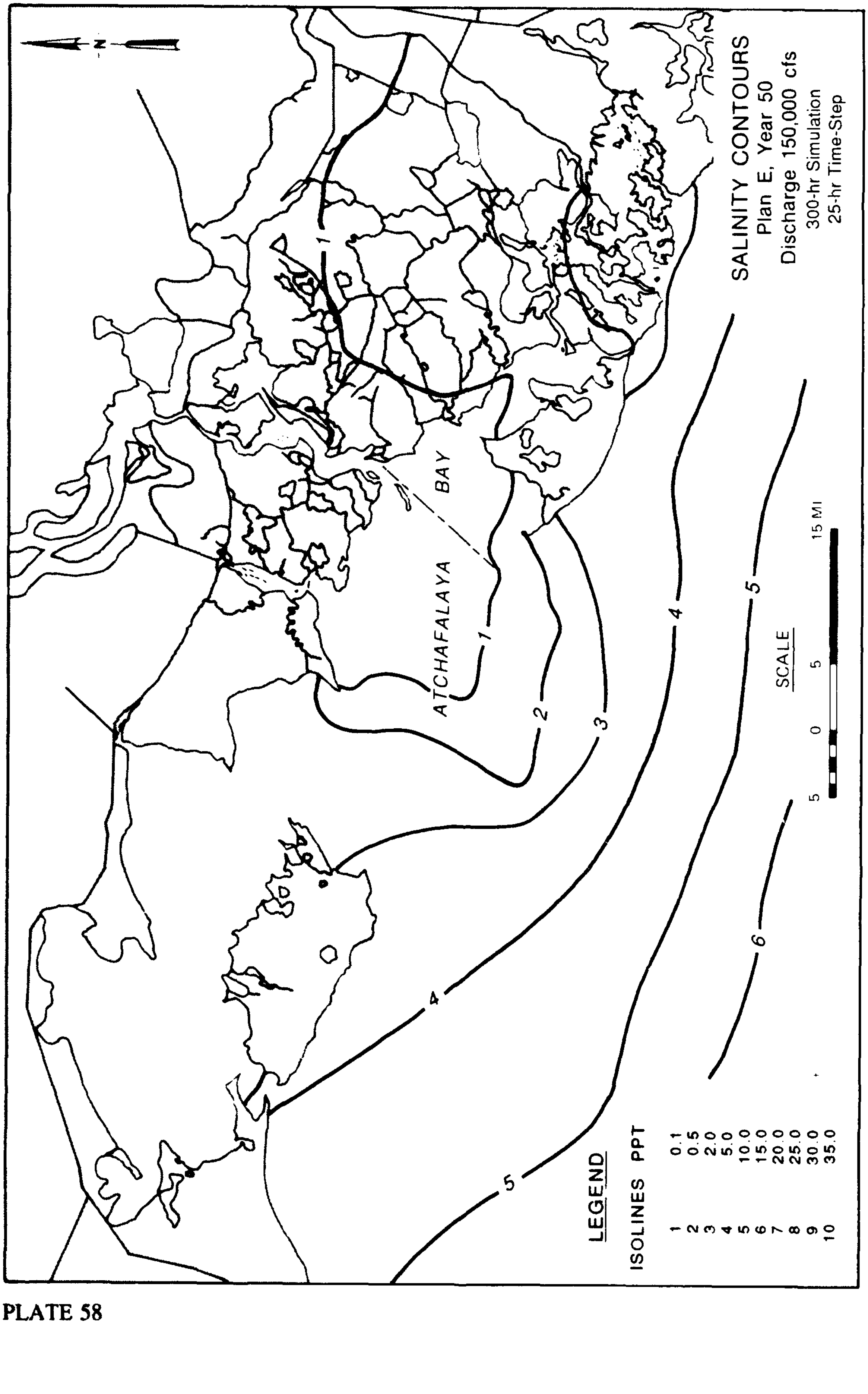
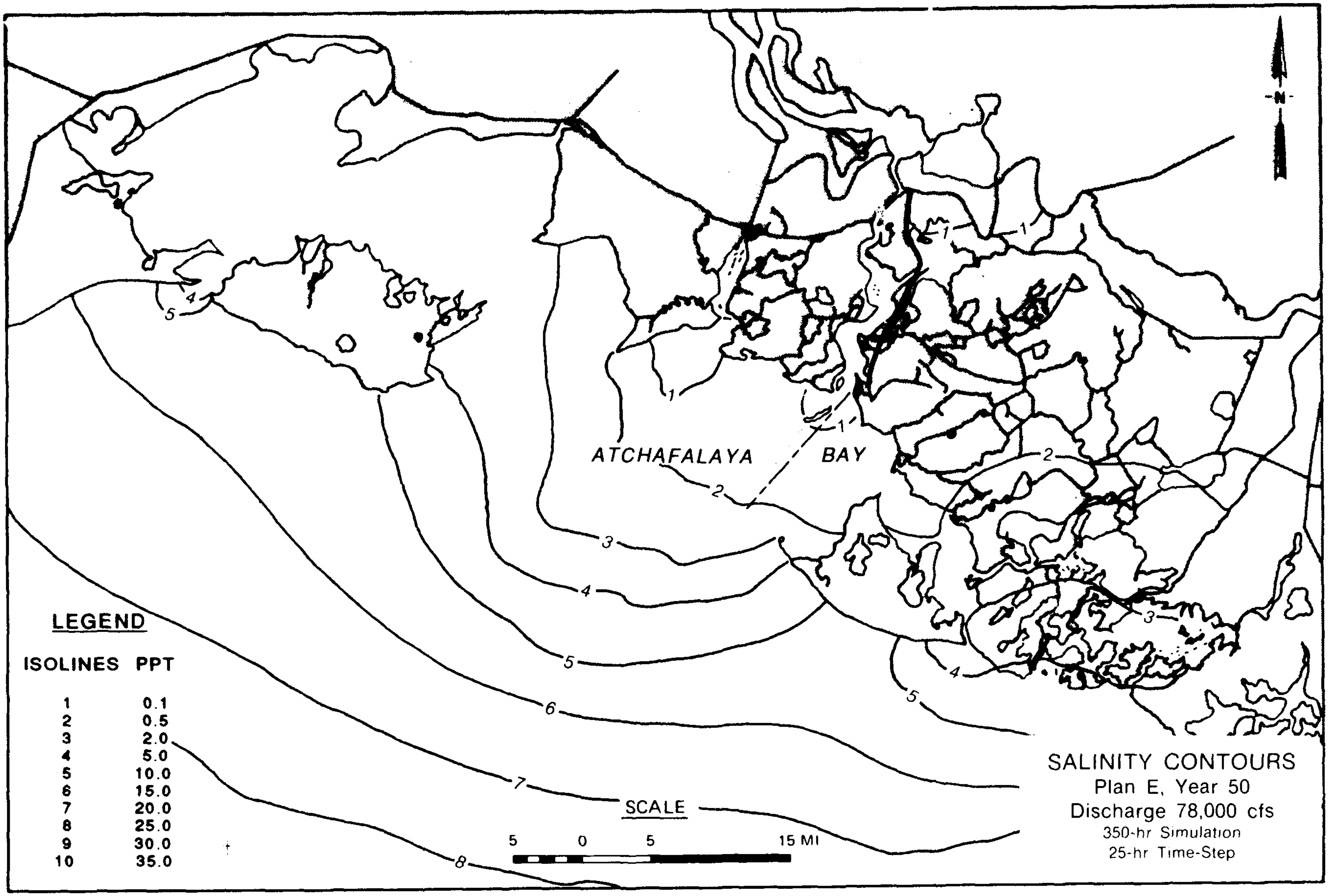
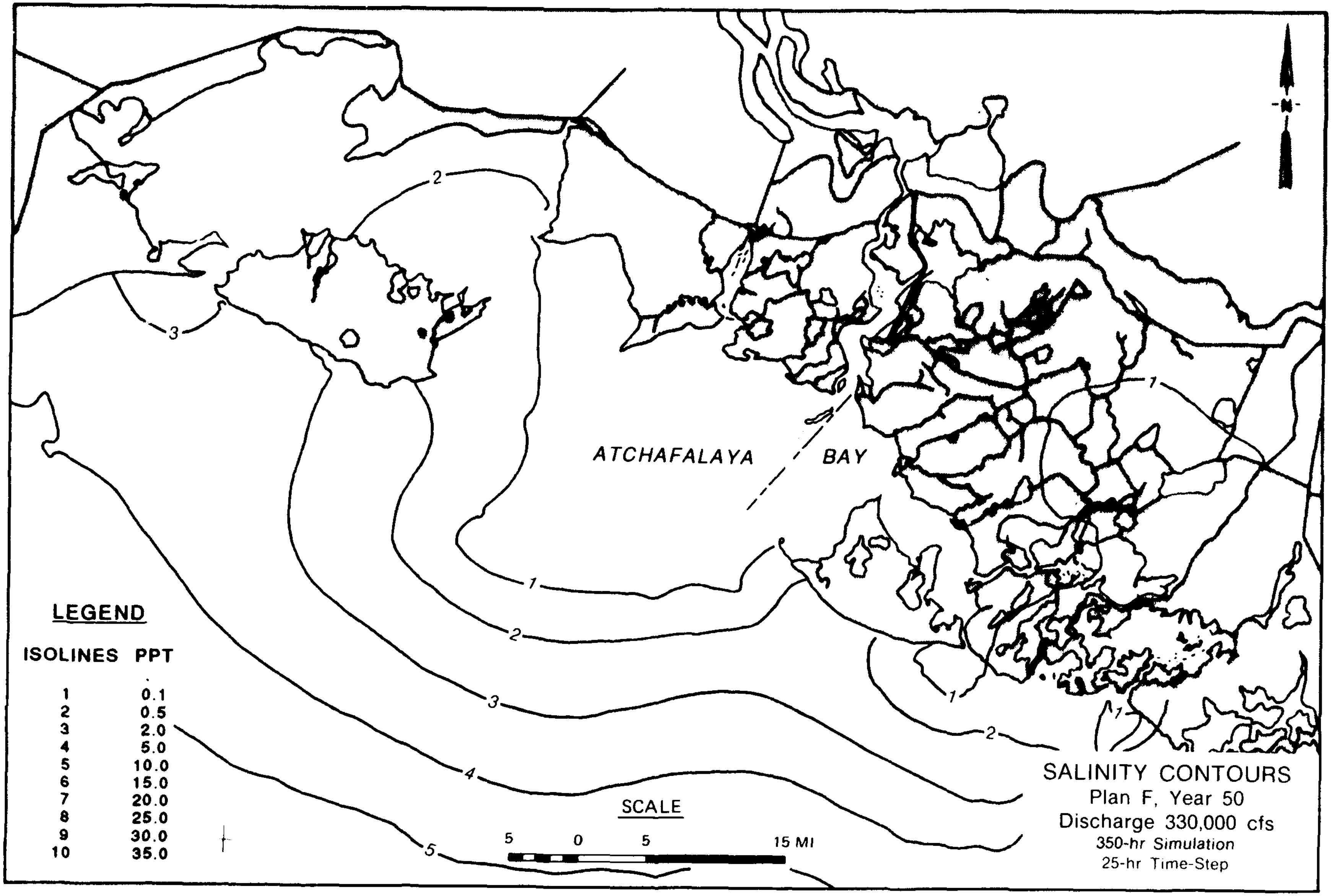
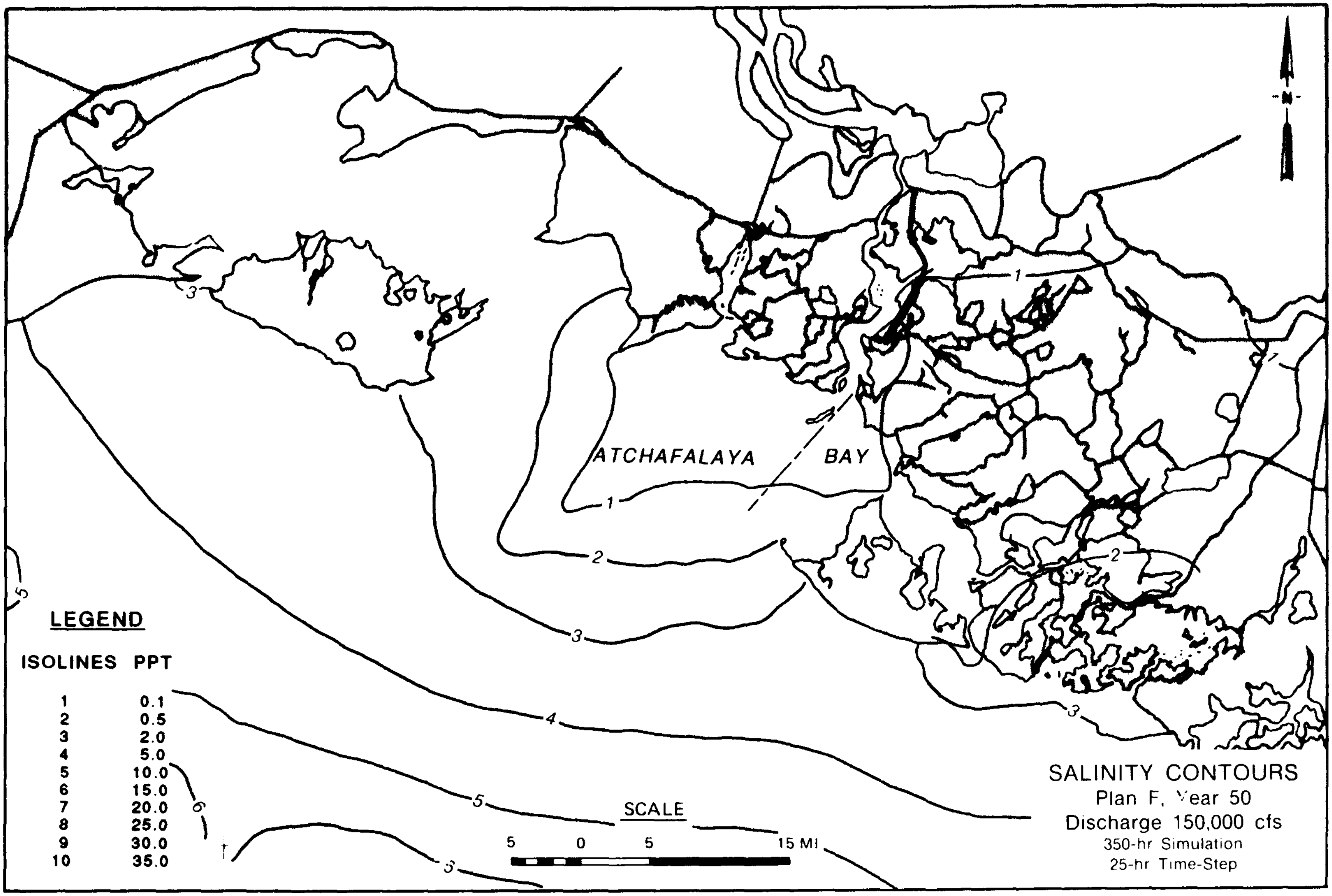

SALINITY CONTOURS
Plan E, Year 50
Discharge 150,000 cfs
300-hr Simulation
25-hr Time-Step
ATCHAFALAYA
BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
N
1
2
3
4
5
6

PLATE 58


N
ATCHAFALAYA
BAY
1
2
3
4
5
6
7
8
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan E, Year 50
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step


N
ATCHAFALAYA BAY
1
2
3
4
5
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan F, Year 50
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step



N
ATCHAFALAYA BAY
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan F, Year 50
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step

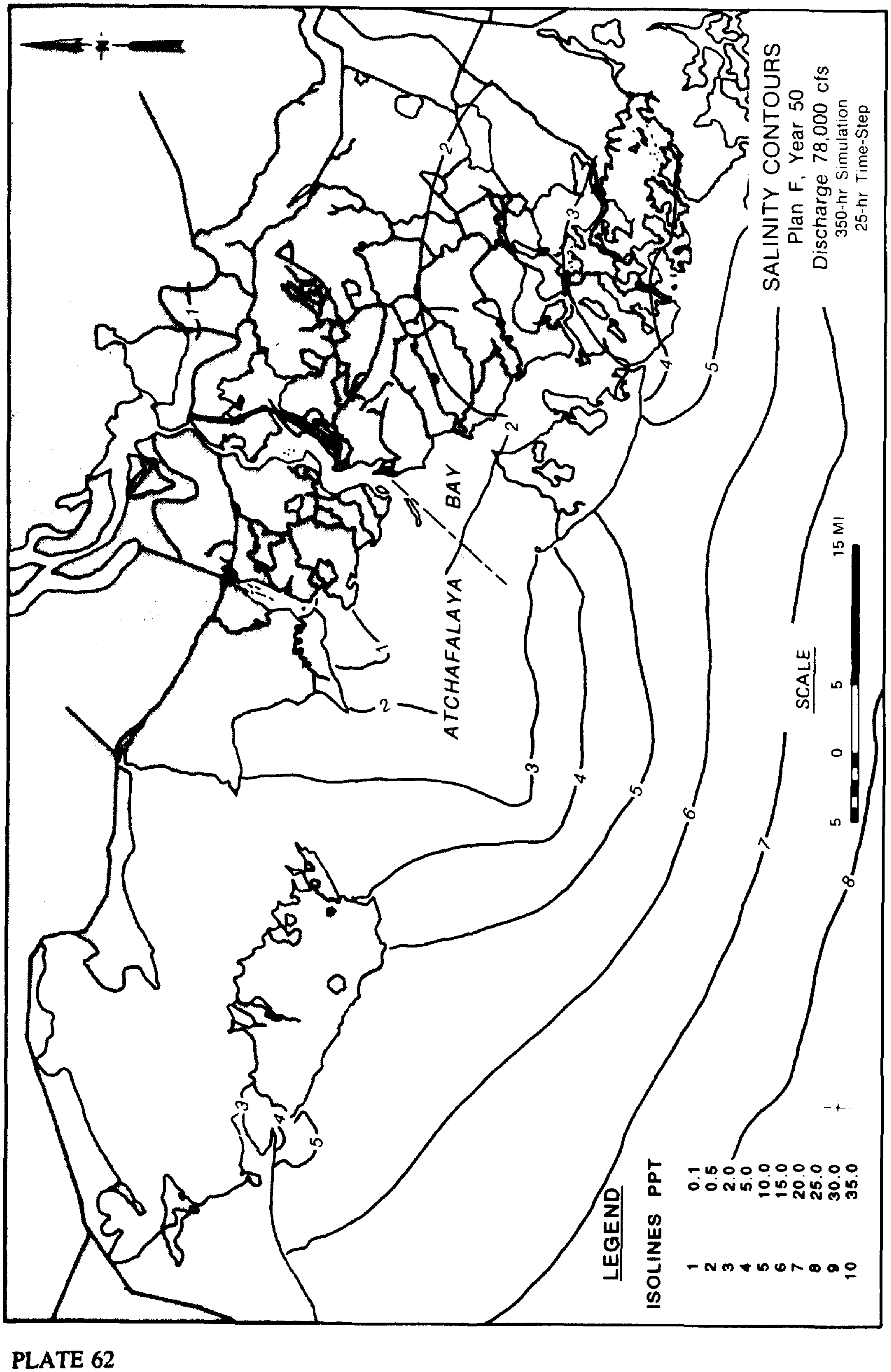
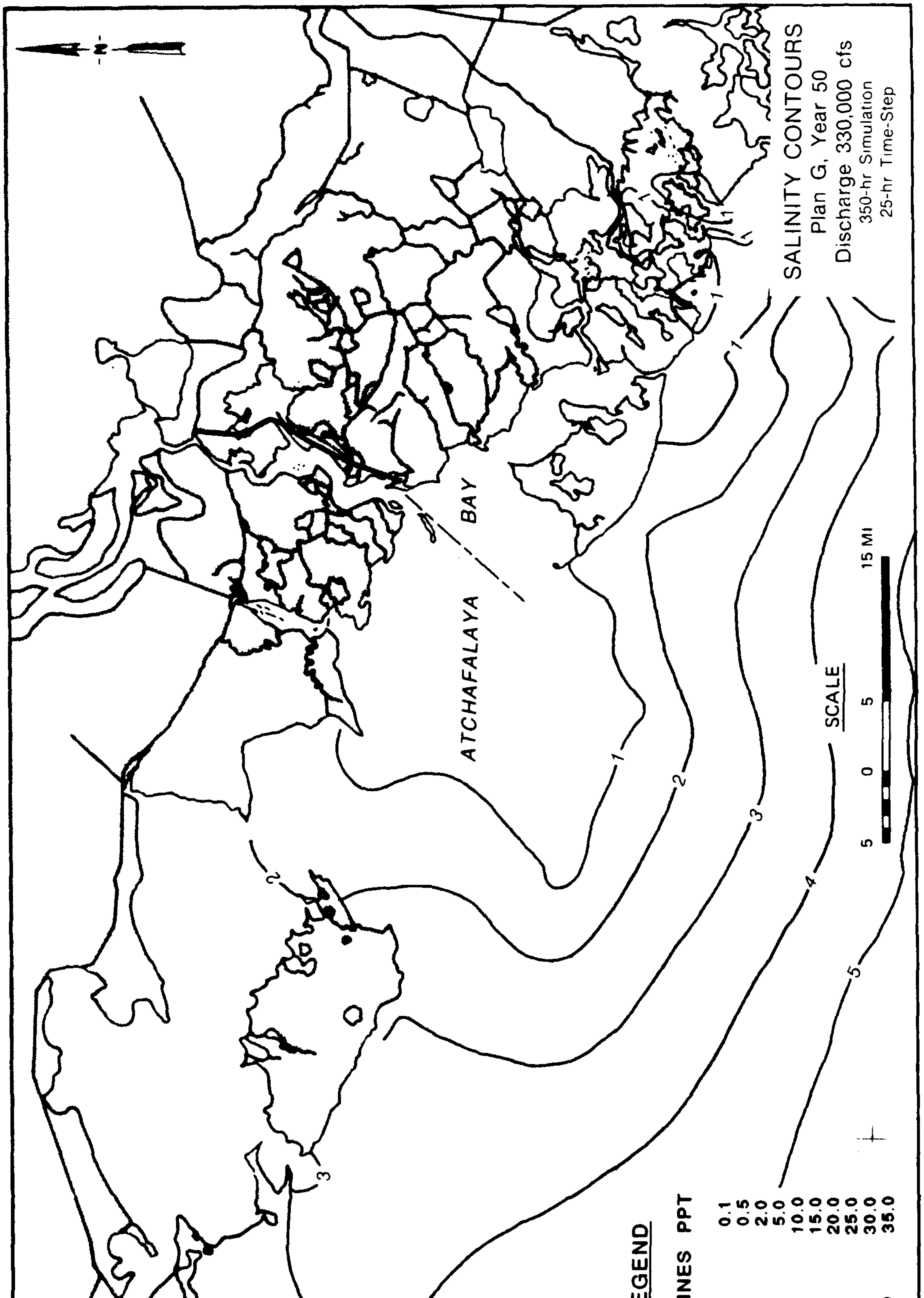

SALINITY CONTOURS
Plan F, Year 50
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA
BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

PLATE 62


SALINITY CONTOURS
Plan G, Year 50
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

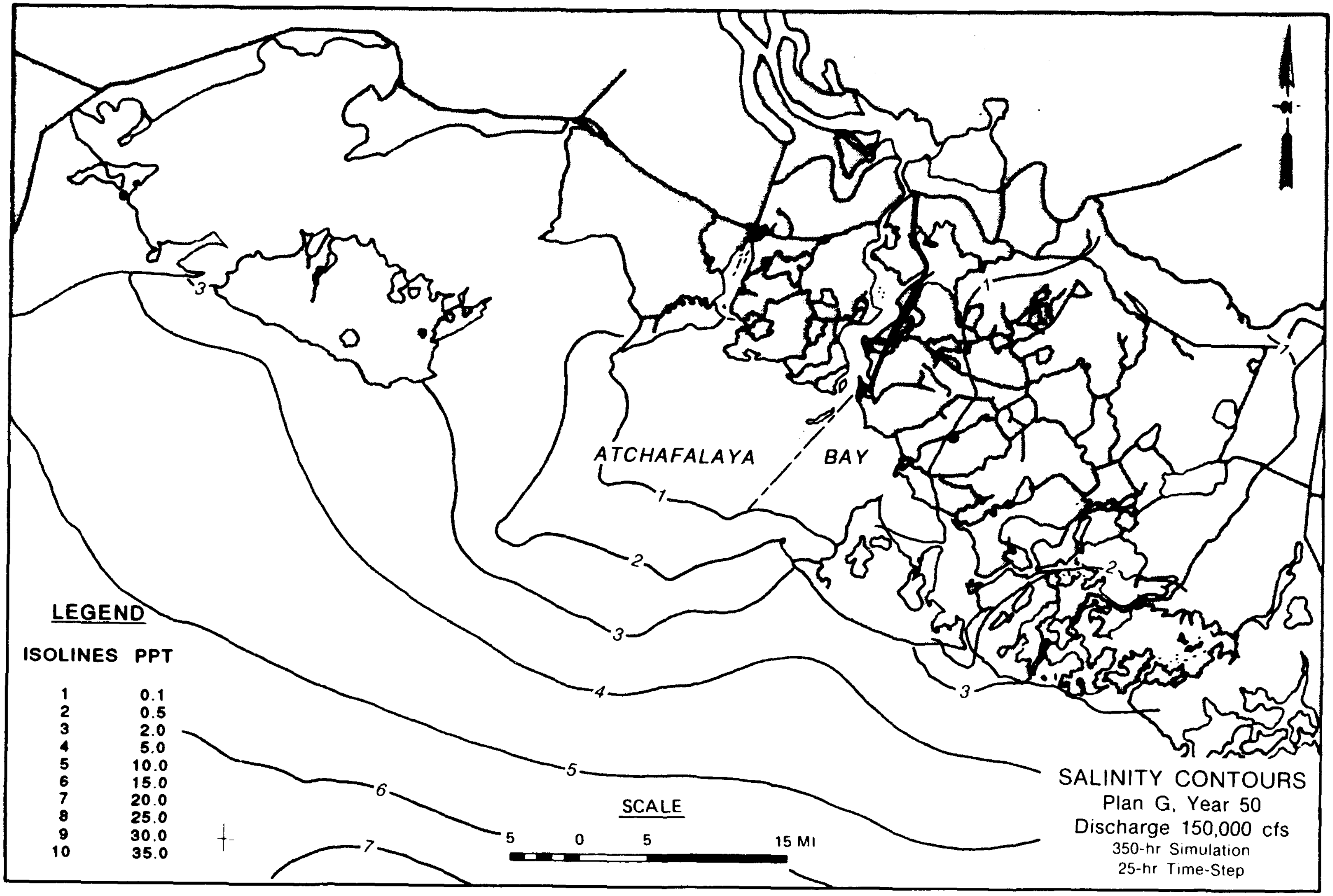
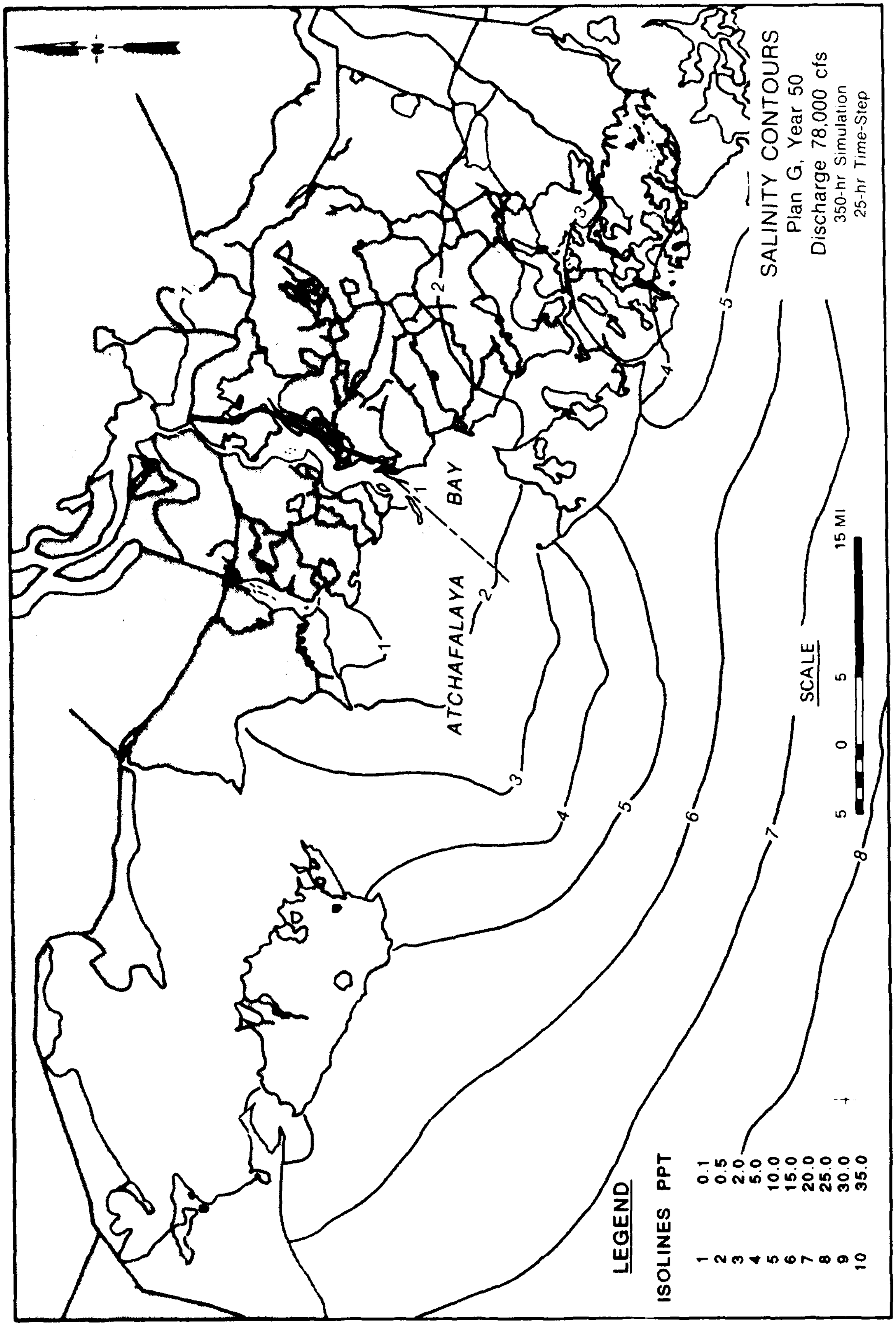

ATCHAFALAYA BAY
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan G, Year 50
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step

PLATE 64


SALINITY CONTOURS
Plan G, Year 50
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA
BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0

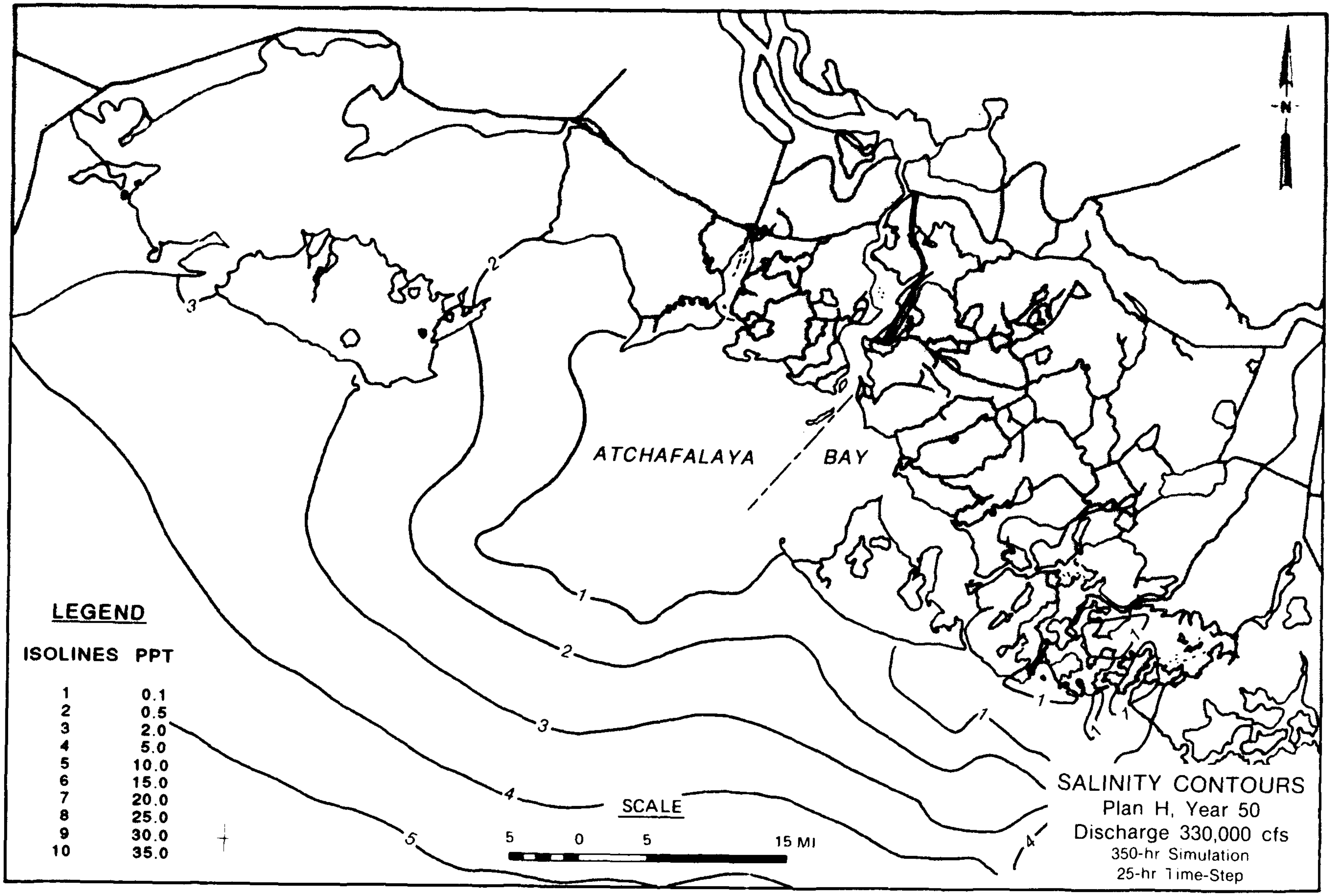
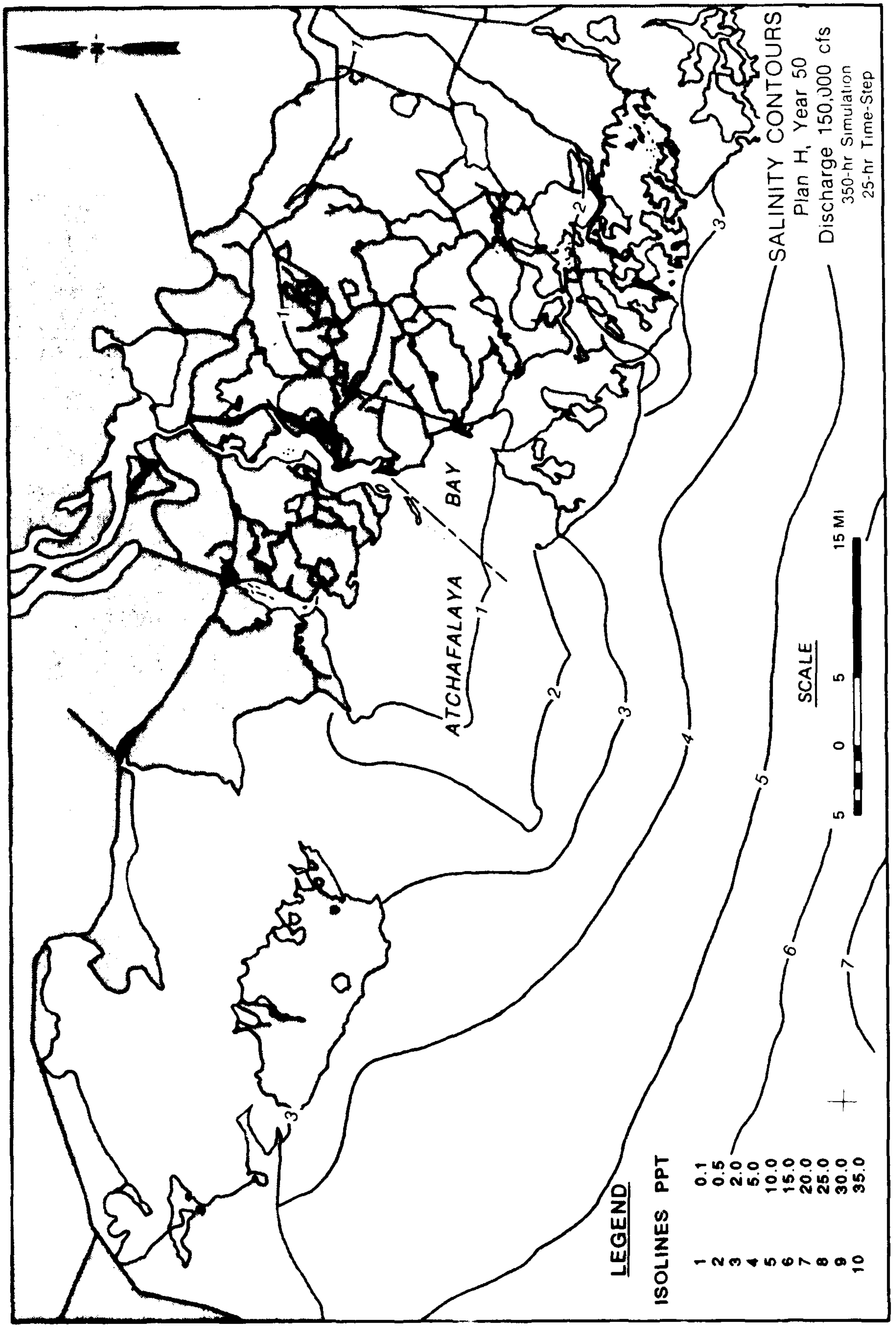
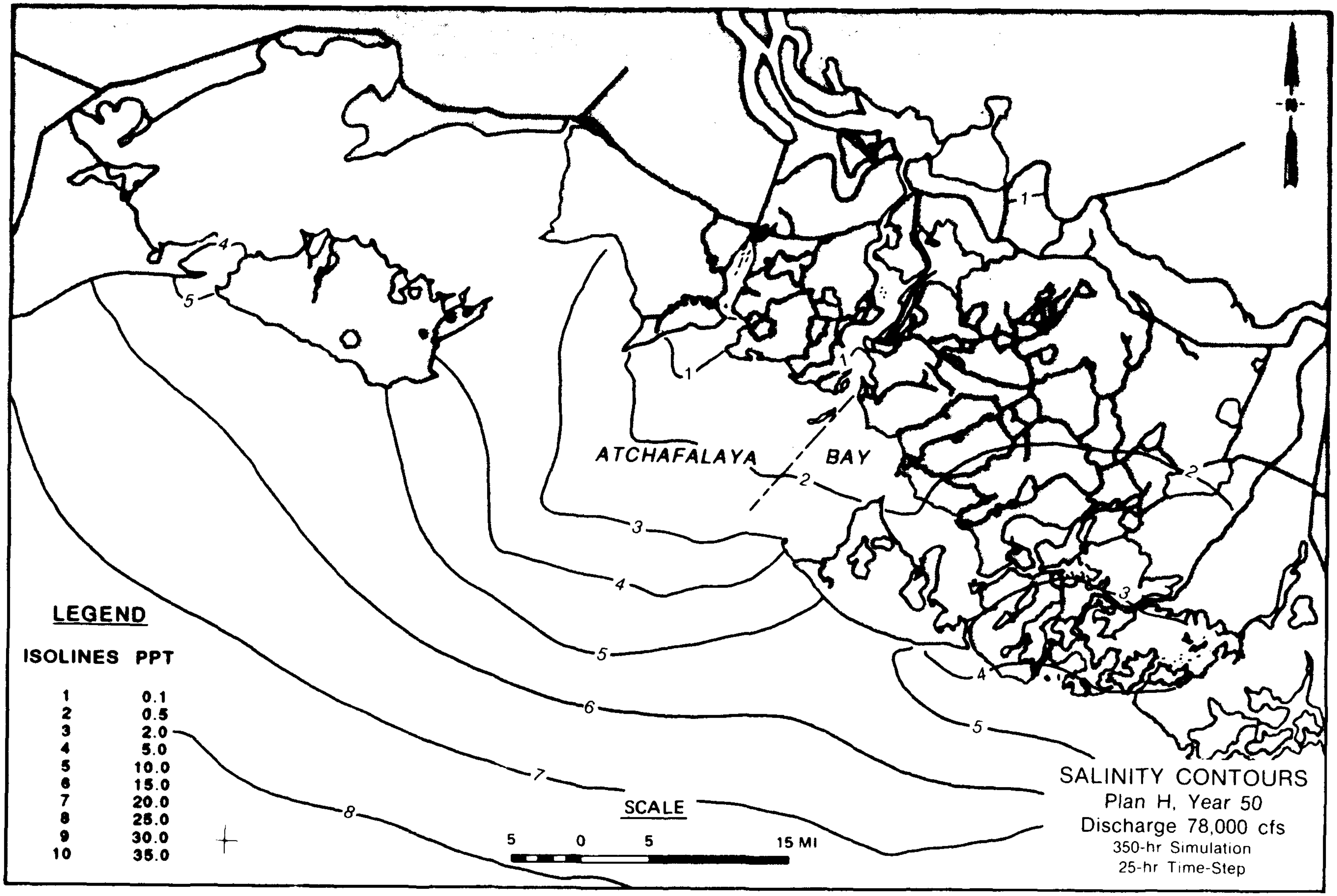

N
ATCHAFALAYA
BAY
1
2
3
4
5
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0
SCALE
5 0 5 15 MI
SALINITY CONTOURS
Plan H, Year 50
Discharge 330,000 cfs
350-hr Simulation
25-hr Time-Step

PLATE 66


SALINITY CONTOURS
Plan H, Year 50
Discharge 150,000 cfs
350-hr Simulation
25-hr Time-Step
ATCHAFALAYA BAY
SCALE
5 0 5 15 MI
LEGEND
ISOLINES PPT
1 0.1
2 0.5
3 2.0
4 5.0
5 10.0
6 15.0
7 20.0
8 25.0
9 30.0
10 35.0



SALINITY CONTOURS
Plan H, Year 50
Discharge 78,000 cfs
350-hr Simulation
25-hr Time-Step